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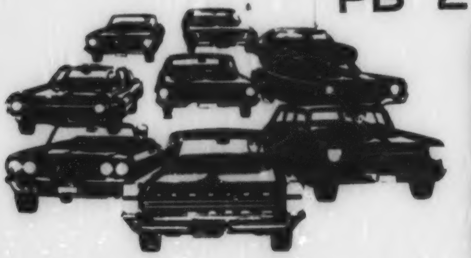

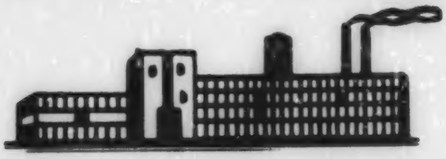

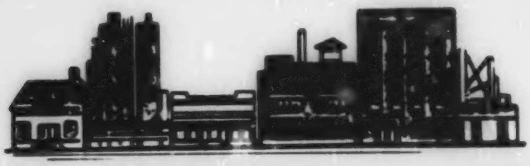

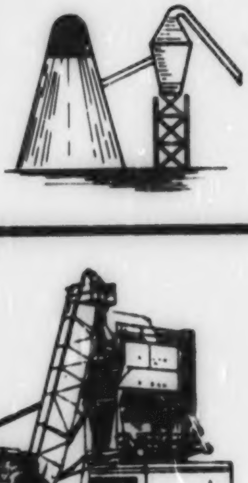

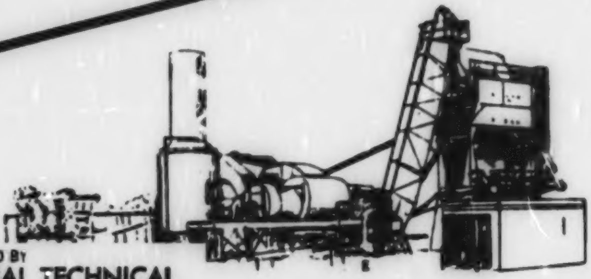

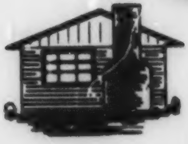

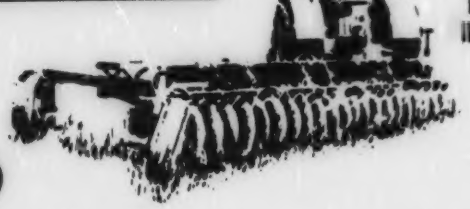

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Emission data obtained from source tests, material balance studies, engineering estimates, etc., have been compiled for use by individuals and groups responsible for conducting air pollution emission inventories. Emission factors given in this document, the result of the expansion and continuation of earlier work, cover most of the common emission categories: fuel combustion by stationary and mobile sources; combustion of solid wastes; evaporation of fuels, solvents, and other volatile substances; various industrial processes; and miscellaneous sources. When no specific source-test data are available, these factors can be used to estimate the quantities of primary pollutants (particulates, CO, SO_2, NO_x, and hydrocarbons) being released from a source or source group.

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COMPILATION OF AIR POLLUTANT EMISSION FACTORS

Third Edition

(Including Supplements 1-7)

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
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August 1977

2<

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3<

PREFACE

This document reports data available on those atmospheric emissions for which sufficient information exists to establish realistic emission factors. The information contained herein is based on Public Health Service Publication 999-AP-42, *Compilation of Air Pollutant Emission Factors*, by R.L. Duprey, and on three revised and expanded editions of *Compilation of Air Pollutant Emission Factors* that were published by the Environmental Protection Agency in February 1972, April 1973, and February 1976. This document is the third edition and includes the supplements issued in July 1973, September 1973, July 1974, January 1975, December 1975, April 1976, and April 1977 (see page iv). It contains no new information not already presented in the previous issuances.

Chapters and sections of this document have been arranged in a format that permits easy and convenient replacement of material as information reflecting more accurate and refined emission factors is published and distributed. To speed dissemination of emission information, chapters or sections that contain new data will be issued—separate from the parent report—whenever they are revised.

To facilitate the addition of future materials, the punched, loose-leaf format was selected. This approach permits the document to be placed in a three-ring binder or to be secured by rings, rivets, or other fasteners: future supplements or revisions can then be easily inserted. The lower left- or right-hand corner of each page of the document bears a notation that indicates the date the information was issued.

Information on the availability of future supplements to *Compilation of Air Pollutant Emission Factors* can be obtained from the Environmental Protection Agency, Library Services, MD-35, Research Triangle Park, N.C. 27711 (Comm. Telephone: 919-541-2777, FTS: 629-2777).

Comments and suggestions regarding this document should be directed to the attention of Director, Monitoring and Data Analysis Division, Office of Air Quality Planning and Standards, Environmental Protection Agency, Research Triangle Park, N.C. 27711.

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5<

PUBLICATIONS IN SERIES

Issuance		Release Date
Compilation of Air Pollutant Emission Factors (second edition)		4/73
Supplement No. 1		7/73
Section 4.3	Storage of Petroleum Products	
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Supplement No. 2		9/73
Introduction		
Section 3.1.1	Average Emission Factors for Highway Vehicles	
Section 3.1.2	Light-Duty, Gasoline-Powered Vehicles	
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Introduction		
Section 1.4	Natural Gas Combustion	
Section 1.5	Liquified Petroleum Gas Combustion	
Section 1.6	Wood/Bark Waste Combustion in Boilers	
Section 2.5	Sewage Sludge Incineration	
Section 7.6	Lead Smelting	
Section 7.11	Secondary Lead Smelting	
Section 10.1	Chemical Wood Pulping	
Section 10.2	Pulpboard	
Section 10.3	Plywood Veneer and Layout Operations	
Supplement No. 4		1/75
Section 3.2.3	Inboard-Powered Vessels	
Section 3.2.5	Small, General Utility Engines	
Section 3.2.6	Agricultural Equipment	
Section 3.2.7	Heavy-Duty Construction Equipment	
Section 3.2.8	Snowmobiles	
Section 3.3.1	Stationary Gas Turbines for Electric Utility Power Plants	
Section 3.3.3	Gasoline and Diesel Industrial Engines	
Chapter 11	Miscellaneous Sources	
Appendix B	Emission Factors and New Source Performance Standards	
Appendix C	NEDS Source Classification Codes and Emission Factor Listing	
Supplement No. 5		12/75
Section 1.7	Lignite Combustion	
Section 3.1.1	Average Emission Factors for Highway Vehicles	
Section 3.1.2	Light-Duty, Gasoline-Powered Vehicles (Automobiles)	
Section 3.1.3	Light-Duty, Diesel-Powered Vehicles	
Section 3.1.4	Light-Duty, Gasoline-Powered Trucks and Heavy-Duty, Gasoline-Powered Vehicles	
Section 3.1.5	Heavy-Duty, Diesel-Powered Vehicles	
Section 5.6	Explosives	
Section 11.2	Fugitive Dust Sources	
Appendix C	NEDS Source Classification Codes and Emission Factor Listing	
Appendix D	Projected Emission Factors for Highway Vehicles	

6<

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Supplement No. 6		4/76
Section 1.3	Fuel Oil Combustion	
Section 2.4	Open Burning	
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Section 6.1	Alfalfa Dehydrating	
Section 6.12	Sugar Cane Processing	
Section 9.2	Natural Gas Processing	
Section 10.4	Woodworking Operations	
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Section 1.2	Anthracite Coal Combustion	
Section 1.3	Fuel Oil Combustion	
Section 1.5	Liquefied Petroleum Gas Combustion	
Section 1.8	Bagasse Combustion in Sugar Mills	
Section 1.9	Residential Fireplaces	
Section 2.4	Open Burning	
Section 4.1	Dry Cleaning	
Section 4.3	Storage of Petroleum Liquids	
Section 4.4	Transportation and Marketing of Petroleum Liquids	
Section 5.1	Adipic Acid	
Section 5.3	Carbon Black	
Section 5.4	Charcoal	
Section 5.12	Phthalic Anhydride	
Section 6.4	Feed and Grain Mills and Elevators	
Section 6.6	Fish Processing	
Section 8.6	Portland Cement Manufacturing	
Section 8.15	Lime Manufacturing	
Section 10.1.3	Acid Sulfite Pulping	
Appendix B	Emission Factors and New Source Performance Standards	

7<

CONTENTS

Page

LIST OF TABLES xvii
LIST OF FIGURES xxi
ABSTRACT xxiii
INTRODUCTION 1
1. EXTERNAL COMBUSTION SOURCES 1.1-1
  1.1 BITUMINOUS COAL COMBUSTION 1.1-1
    1.1.1 General 1.1-1
    1.1.2 Emissions and Controls 1.1-1
      References for Section 1.1 . . . . . 1.1-4
  1.2 ANTHRACITE COAL COMBUSTION 1.2-1
    1.2.1 General 1.2-1
    1.2.2 Emissions and Controls 1.2-1
      References for Section 1.2 . . . . . 1.2-4
  1.3 FUEL OIL COMBUSTION 1.3-1
    1.3.1 General 1.3-1
    1.3.2 Emissions 1.3-1
    1.3.3 Controls **1.3-3**
      References for Section 1.3 . . . . . 1.3-4
  1.4 NATURAL GAS COMBUSTION 1.4-1
    1.4.1 General 1.4-1
    1.4.2 Emissions and Controls 1.4-1
      References for Section 1.4 . . . . . 1.4-3
  1.5 LIQUEFIED PETROLEUM GAS COMBUSTION 1.5-1
    1.5.1 General 1.5-1
    1.5.2 Emissions 1.5-1
      References for Section 1.5 . . . . . 1.5-1
  1.6 WOOD WASTE COMBUSTION IN BOILERS 1.6-1
    1.6.1 General 1.6-1
    1.6.2 Firing Practices 1.6-1
    1.6.3 Emissions 1.6-1
      References for Section 1.6 . . . . . 1.6-2
  1.7 LIGNITE COMBUSTION 1.7-1
    1.7.1 General 1.7-1
    1.7.2 Emissions and Controls 1.7-1
      References for Section 1.7 . . . . . 1.7-2
  1.8 BAGASSE COMBUSTION IN SUGAR MILLS **1.8-1**
    1.8.1 General **1.8-1**
    1.8.2 Emissions and Controls **1.8-1**
      Reference for Section 1.8 . . . . . **1.8-2**
  1.9 RESIDENTIAL FIREPLACES **1.9-1**
    1.9.1 General **1.9-1**
    1.9.2 Emissions **1.9-1**
      References for Section 1.9 . . . . . **1.9-2**
2. SOLID WASTE DISPOSAL 2.1-1
  2.1 REFUSE INCINERATION 2.1-2
    2.1.1 Process Description 2.1-2
    2.1.2 Definitions of Incinerator Categories 2.1-2
    2.1.3 Emissions and Controls 2.1-4
      References for Section 2.1 . . . . . 2.1-5

8<

CONTENTS — (Continued)

Page
2.2 AUTOMOBILE BODY INCINERATION 2.2-1
  2.2.1 Process Description 2.2-1
  2.2.2 Emissions and Controls 2.2-1
    References for Section 2.2 . . . . . 2.2-2
2.3 CONICAL BURNERS 2.3-1
  2.3.1 Process Description 2.3-1
  2.3.2 Emissions and Controls 2.3-1
    References for Section 2.3 . . . . . 2.3-3
2.4 OPEN BURNING 2.4-1
  2.4.1 General 2.4-1
  2.4.2 Emissions 2.4-1
    References for Section 2.4 . . . . . 2.4-4
2.5 SEWAGE SLUDGE INCINERATION 2.5-1
  2.5.1 Process Description 2.5-1
  2.5.2 Emissions and Controls 2.5-1
    References for Section 2.5 . . . . . 2.5-2
3. INTERNAL COMBUSTION ENGINE SOURCES 3.1.1-1
DEFINITIONS USED IN CHAPTER 3 . . . . . 3.1.1-1
3.1 HIGHWAY VEHICLES 3.1.1-2
  3.1.1 Average Emission Factors for Highway Vehicles 3.1.1-3
  3.1.2 Light-Duty, Gasoline-Powered Vehicles (Automobiles) 3.1.2-1
  3.1.3 Light-Duty, Diesel-Powered Vehicles 3.1.3-1
  3.1.4 Light-Duty, Gasoline-Powered Trucks and Heavy-Duty, Gasoline-Powered Vehicles 3.1.4-1
  3.1.5 Heavy-Duty, Diesel-Powered Vehicles 3.1.5-1
  3.1.6 Gaseous-Fueled Vehicles 3.1.6-1
  3.1.7 Motorcycles 3.1.7-1
3.2 OFF-HIGHWAY, MOBILE SOURCES 3.2.1-1
  3.2.1 Aircraft 3.2.1-1
  3.2.2 Locomotives 3.2.2-1
  3.2.3 Inboard-Powered Vessels 3.2.3-1
  3.2.4 Outboard-Powered Vessels 3.2.4-1
  3.2.5 Small, General Utility Engines 3.2.5-1
  3.2.6 Agricultural Equipment 3.2.6-1
  3.2.7 Heavy-Duty Construction Equipment 3.2.7-1
  3.2.8 Snowmobiles 3.2.8-1
3.3 OFF-HIGHWAY STATIONARY SOURCES 3.3.1-1
  3.3.1 Stationary Gas Turbines for Electric Utility Power Plants 3.3.1-1
  3.3.2 Heavy-Duty, Natural-Gas-Fired Pipeline Compressor Engines. 3.3.2-1
  3.3.3 Gasoline and Diesel Industrial Engines 3.3.3-1
4. EVAPORATION LOSS SOURCES 4.1-1
4.1 DRY CLEANING 4.1-1
  4.1.1 General 4.1-1
  4.1.2 Emissions and Controls 4.1-3
    References for Section 4.1 . . . . . 4.1-4
4.2 SURFACE COATING 4.2-1
  4.2.1 Process Description 4.2-1
  4.2.2 Emissions and Controls 4.2-1
    References for Section 4.2 . . . . . 4.2-2
4.3 STORAGE OF PETROLEUM LIQUIDS 4.3-1
  4.3.1 Process Description 4.3-1
    4.3.1.1 Fixed Roof Tanks 4.3-1
    4.3.1.2 Floating Roof Tanks 4.3-1
    4.3.1.3 Variable Vapor Space Tanks 4.3-4
    4.3.1.4 Pressure Tanks 4.3-5

9<

CONTENTS – (Continued)

Page
4.3.2 Emissions and Controls . . . 4.3-5
4.3.2.1 Fixed Roof Tanks . . . 4.3-6
4.3.2.2 Floating Roof Tanks . . . 4.3-12
4.3.2.3 Variable Vapor Space Systems . . . 4.3-13
4.3.2.4 Pressure Tanks . . . 4.3-14
4.3.3 Emission Factors . . . 4.3-14
4.3.3.1 Sample Calculation . . . 4.3-16
References for Section 4.3 . . . 4.3-17
4.4 TRANSPORTATION AND MARKETING OF PETROLEUM LIQUIDS . . . 4.4-1
4.4.1 Process Description . . . 4.4-1
4.4.2 Emissions and Controls . . . 4.4-1
4.4.2.1 Large Storage Tanks . . . 4.4-1
4.4.2.2 Marine Vessels, Tank Cars, and Tanktrucks . . . 4.4-1
4.4.2.3 Sample Calculation . . . 4.4-8
4.4.2.4 Service Stations . . . 4.4-10
4.4.2.5 Motor Vehicle Refueling . . . 4.4-11
References for Section 4.4 . . . 4.4-12
5. CHEMICAL PROCESS INDUSTRY . . . 5.1-1
5.1 ADIPIC ACID . . . 5.1-1
5.1.1 General . . . 5.1-1
5.1.2 Emissions and Controls . . . 5.1-2
References for Section 5.1 . . . 5.1-4
5.2 AMMONIA . . . 5.2-1
5.2.1 Process Description . . . 5.2-1
5.2.2 Emissions and Controls . . . 5.2-1
References for Section 5.2 . . . 5.2-2
5.3 CARBON BLACK . . . 5.3-1
5.3.1 Process Description . . . 5.3-1
5.3.1.1 Furnace Process . . . 5.3-1
5.3.1.2 Thermal Process . . . 5.3-1
5.3.1.3 Channel Process . . . 5.3-3
5.3.2 Emissions and Controls . . . 5.3-3
References for Section 5.3 . . . 5.3-5
5.4 CHARCOAL . . . 5.4-1
5.4.1 Process Description . . . 5.4-1
5.4.2 Emissions and Controls . . . 5.4-1
References for Section 5.4 . . . 5.4-1
5.5 CHLOR-ALKALI . . . 5.5-1
5.5.1 Process Description . . . 5.5-1
5.5.2 Emissions and Controls . . . 5.5-1
References for Section 5.5 . . . 5.5-1
5.6 EXPLOSIVES . . . 5.6-1
5.6.1 General . . . 5.6-1
5.6.2 TNT Production . . . 5.6-1
5.6.3 Nitrocellulose Production . . . 5.6-1
5.6.4 Emissions . . . 5.6-1
References for Section 5.6 . . . 5.6-2
5.7 HYDROCHLORIC ACID . . . 5.7-1
5.7.1 Process Description . . . 5.7-1
5.7.2 Emissions . . . 5.7-1
References for Section 5.7 . . . 5.7-1
5.8 HYDROFLUORIC ACID . . . 5.8-1
5.8.1 Process Description . . . 5.8-1

CONTENTS – (Continued)

Page

- 5.8.2 Emissions and Controls . . . 5.8-1
  - References for Section 5.8 . . . 5.8-2
- 5.9 NITRIC ACID . . . 5.9-1
  - 5.9.1 Process Description . . . 5.9-1
    - 5.9.1.1 Weak Acid Production . . . 5.9-1
    - 5.9.1.2 High-Strength Acid Production . . . 5.9-1
  - 5.9.2 Emissions and Controls . . . 5.9-3
  - References for Section 5.9 . . . 5.9-4
- 5.10 PAINT AND VARNISH . . . 5.10-1
  - 5.10.1 Paint Manufacturing . . . 5.10-1
  - 5.10.2 Varnish Manufacturing . . . 5.10-1
  - References for Section 5.10 . . . 5.10-2
- 5.11 PHOSPHORIC ACID . . . 5.10-2
  - 5.11.1 Wet Process . . . 5.11-1
  - 5.11.2 Thermal Process . . . 5.11-1
  - References for Section 5.11 . . . 5.11-2
- 5.12 PHTHALIC ANHYDRIDE . . . 5.12-1
  - 5.12.1 General . . . 5.12-1
  - 5.12.2 Emissions and Controls . . . 5.12-2
  - Reference for Section 5.12 . . . 5.12-5
- 5.13 PLASTICS . . . 5.13-1
  - 5.13.1 Process Description . . . 5.13-1
  - 5.13.2 Emissions and Controls . . . 5.13-1
  - References for Section 5.13 . . . 5.13-2
- 5.14 PRINTING INK . . . 5.14-1
  - 5.14.1 Process Description . . . 5.14-1
  - 5.14.2 Emissions and Controls . . . 5.14-2
  - References for Section 5.14 . . . 5.14-2
- 5.15 SOAP AND DETERGENTS . . . 5.15-1
  - 5.15.1 Soap Manufacture . . . 5.15-1
  - 5.15.2 Detergent Manufacture . . . 5.15-1
  - References for Section 5.15 . . . 5.15-2
- 5.16 SODIUM CARBONATE . . . 5.16-1
  - 5.16.1 Process Description . . . 5.16-1
  - 5.16.2 Emissions . . . 5.16-1
  - References for Section 5.16 . . . 5.16-2
- 5.17 SULFURIC ACID . . . 5.17-1
  - 5.17.1 Process Description . . . 5.17-1
    - 5.17.1.1 Elemental Sulfur-Burning Plants . . . 5.17-1
    - 5.17.1.2 Spent-Acid and Hydrogen Sulfide Burning Plants . . . 5.17-4
    - 5.17.1.3 Sulfide Ores and Smelter Gas Plants . . . 5.17-4
  - 5.17.2 Emissions and Controls . . . 5.17-4
    - 5.17.2.1 Sulfur Dioxide . . . 5.17-4
    - 5.17.2.2 Acid Mist . . . 5.17-5
  - References for Section 5.17 . . . 5.17-8
- 5.18 SULFUR . . . 5.18-1
  - 5.18.1 Process Description . . . 5.18-1
  - 5.18.2 Emissions and Controls . . . 5.18-1
  - References for Section 5.18 . . . 5.18-2
- 5.19 SYNTHETIC FIBERS . . . 5.19-1
  - 5.19.1 Process Description . . . 5.19-1
  - 5.19.2 Emissions and Controls . . . 5.19-1
  - References for Section 5.19 . . . 5.19-2

11<

CONTENTS–(Continued)

Page

5.20 SYNTHETIC RUBBER 5.20-1
5.20.1 Process Description 5.20-1
5.20.2 Emissions and Controls 5.20-1
References for Section 5.20 5.20-2
5.21 TEREPHTHALIC ACID 5.21-1
5.21.1 Process Description 5.21-1
5.21.2 Emissions 5.21-1
References for Section 5.21 5.21-1
6. FOOD AND AGRICULTURAL INDUSTRY 6.1-1
6.1 ALFALFA DEHYDRATING 6.1-1
6.1.1 General 6.1-1
6.1.2 Emissions and Controls 6.1-1
References for Section 6.1 6.1-
6.2 COFFEE ROASTING 6.2
6.2.1 Process Description 6.2-1
6.2.2 Emissions 6.2-1
References for Section 6.2 6.2-2
6.3 COTTON GINNING 6.3-1
6.3.1 General 6.3-1
6.3.2 Emissions and Controls 6.3-1
References for Section 6.3 6.3-1
6.4 FEED AND GRAIN MILLS AND ELEVATORS 6.4-1
6.4.1 General 6.4-1
6.4.2 Emissions and Controls 6.4-1
6.4.2.1 Grain Elevators 6.4-1
6.4.2.2 Grain Processing Operations 6.4-3
References for Section 6.4 6.4-6
6.5 FERMENTATION 6.5-1
6.5.1 Process Description 6.5-1
6.5.2 Emissions 6.5-1
References for Section 6.5 6.5-2
6.6 FISH PROCESSING 6.6-1
6.6.1 Process Description 6.6-1
6.6.2 Emissions and Controls 6.6-1
References for Section 6.6 6.6-3
6.7 MEAT SMOKEHOUSES 6.7-1
6.7.1 Process Description 6.7-1
6.7.2 Emissions and Controls 6.7-1
References for Section 6.7 6.7-2
6.8 NITRATE FERTILIZERS 6.8-1
6.8.1 General 6.8-1
6.8.2 Emissions and Controls 6.8-1
References for Section 6.8 6.8-2
6.9 ORCHARD HEATERS 6.9-1
6.9.1 General 6.9-1
6.9.2 Emissions 6.9-1
References for Section 6.9 6.9-4
6.10 PHOSPHATE FERTILIZERS 6.10-1
6.10.1 Normal Superphosphate 6.10-1
6.10.1.1 General 6.10-1
6.10.1.2 Emissions 6.10-2
6.10.2 Triple Superphosphate 6.10-2

CONTENTS – (Continued)

Page
6.10.2.1 General 6.10-2
6.10.2.2 Emissions 6.10-2
6.10.3 Ammonium Phosphate 6.10-2
6.10.3.1 General 6.10-2
6.10.3.2 Emissions 6.10-3
References for Section 6.10 6.10-3
6.11 STARCH MANUFACTURING 6.11-1
6.11.1 Process Description 6.11-1
6.11.2 Emissions 6.11-1
References for Section 6.11 6.11-1
6.12 SUGAR CANE PROCESSING 6.12-1
6.12.1 General 6.12-1
6.12.2 Emissions 6.12-1
References for Section 6.12 6.12-1
7. METALLURGICAL INDUSTRY 7.1-1
7.1 PRIMARY ALUMINUM PRODUCTION 7.1-1
7.1.1 Process Description 7.1-1
7.1.2 Emissions and Controls 7.1-2
References for Section 7.1 7.1-8
7.2 METALLURGICAL COKE MANUFACTURING 7.2-1
7.2.1 Process Description 7.2-1
7.2.2 Emissions 7.2-1
References for Section 7.2 7.2-3
7.3 COPPER SMELTERS 7.3-1
7.3.1 Process Description 7.3-1
7.3.2 Emissions and Controls 7.3-1
References for Section 7.3 7.3-2
7.4 FERROALLOY PRODUCTION 7.4-1
7.4.1 Process Description 7.4-1
7.4.2 Emissions 7.4-1
References for Section 7.4 7.4-2
7.5 IRON AND STEEL MILLS 7.5-1
7.5.1 General 7.5-1
7.5.1.1 Pig Iron Manufacture 7.5-1
7.5.1.2 Steel-Making Processes 7.5-1
7.5.1.3 Scarfing 7.5-1
References for Section 7.5 7.5-6
7.6 LEAD SMELTING 7.6-1
7.6.1 Process Description 7.6-1
7.6.2 Emissions and Controls 7.6-3
References for Section 7.6 7.6-5
7.7 ZINC SMELTING 7.7-1
7.7.1 Process Description 7.7-1
7.7.2 Emissions and Controls 7.7-1
References for Section 7.7 7.7-2
7.8 SECONDARY ALUMINUM OPERATIONS 7.8-1
7.8.1 Process Description 7.8-1
7.8.2 Emissions 7.8-1
References for Section 7.8 7.8-2
7.9 BRASS AND BRONZE INGOTS 7.9-1
7.9.1 Process Description 7.9-1
7.9.2 Emissions and Controls 7.9-1
References for Section 7.9 7.9-2

13<

CONTENTS–(Continued)

Page

7.10 GRAY IRON FOUNDRY 7.10-1
  7.10.1 Process Description 7.10-1
  7.10.2 Emissions 7.10-1
    References for Section 7.10 7.10-2
7.11 SECONDARY LEAD SMELTING 7.11-1
  7.11.1 Process Description 7.11-1
  7.11.2 Emissions and Controls 7.11-1
    References for Section 7.11 7.11-1
7.12 SECONDARY MAGNESIUM SMELTING 7.12-1
  7.12.1 Process Description 7.12-1
  7.12.2 Emissions 7.12-1
    References for Section 7.12 7.12-2
7.13 STEEL FOUNDRIES 7.13-1
  7.13.1 Process Description 7.13-1
  7.13.2 Emissions 7.13-1
    References for Section 7.13 7.13-3
7.14 SECONDARY ZINC PROCESSING 7.14-1
  7.14.1 Process Description 7.14-1
  7.14.2 Emissions 7.14-1
    References for Section 7.14 7.14-2
8. MINERAL PRODUCTS INDUSTRY 8.1-1
8.1 ASPHALTIC CONCRETE PLANTS 8.1-1
  8.1.1 Process Description 8.1-1
  8.1.2 Emissions and Controls 8.1-4
    References for Section 8.1 8.1-5
8.2 ASPHALT ROOFING 8.2-1
  8.2.1 Process Description 8.2-1
  8.2.2 Emissions and Controls 8.2-1
    References for Section 8.2 8.2-2
8.3 BRICKS AND RELATED CLAY PRODUCTS 8.3-1
  8.3.1 Process Description 8.3-1
  8.3.2 Emissions and Controls 8.3-1
    References for Section 8.3 8.3-4
8.4 CALCIUM CARBIDE MANUFACTURING 8.4-1
  8.4.1 Process Description 8.4-1
  8.4.2 Emissions and Controls 8.4-1
    References for Section 8.4 8.4-2
8.5 CASTABLE REFRACTORIES 8.5-1
  8.5.1 Process Description 8.5-1
  8.5.2 Emissions and Controls 8.5-1
    References for Section 8.5 8.5-2
8.6 PORTLAND CEMENT MANUFACTURING 8.6-1
  8.6.1 Process Description 8.6-1
  8.6.2 Emissions and Controls 8.6-1
    References for Section 8.6 8.6-2
8.7 CERAMIC CLAY MANUFACTURING 8.7-1
  8.7.1 Process Description 8.7-1
  8.7.2 Emissions and Controls 8.7-1
    References for Section 8.7 8.7-2
8.8 CLAY AND FLY-ASH SINTERING 8.8-1
  8.8.1 Process Description 8.8-1
  8.8.2 Emissions and Controls 8.8-1
    References for Section 8.8 8.8-2

CONTENTS–(Continued)

Page

8.9 COAL CLEANING 8.9-1
8.9.1 Process Description 8.9-1
8.9.2 Emissions and Controls 8.9-1
References for Section 8.9 . . . . 8.9-2
8.10 CONCRETE BATCHING 8.10-1
8.10.1 Process Description 8.10-1
8.10.2 Emissions and Controls 8.10-1
References for Section 8.10 . . . . 8.10-2
8.11 FIBER GLASS MANUFACTURING 8.11-1
8.11.1 Process Description 8.11-1
8.11.1.1 Textile Products 8.11-1
8.11.1.2 Wool Products 8.11-1
8.11.2 Emissions and Controls 8.11-1
References for Section 8.11 . . . . 8.11-4
8.12 FRIT MANUFACTURING 8.12-1
8.12.1 Process Description 8.12-1
8.12.2 Emissions and Controls 8.12-1
References for Section 8.12 . . . . 8.12-2
8.13 GLASS MANUFACTURING 8.13-1
8.13.1 Process Description 8.13-1
8.13.2 Emissions and Controls 8.13-1
References for Section 8.13 . . . . 8.13-2
8.14 GYPSUM MANUFACTURING 8.14-1
8.14.1 Process Description 8.14-1
8.14.2 Emissions 8.14-1
References for Section 8.14 . . . . 8.14-2
8.15 LIME MANUFACTURING 8.15-1
8.15.1 General 8.15-1
8.15.2 Emissions and Controls 8.15-3
References for Section 8.15 . . . . 8.15-5
8.16 MINERAL WOOL MANUFACTURING 8.16-1
8.16.1 Process Description 8.16-1
8.16.2 Emissions and Controls 8.16-1
References for Section 8.16 . . . . 8.16-2
8.17 PERLITE MANUFACTURING 8.17-1
8.17.1 Process Description 8.17-1
8.17.2 Emissions and Controls 8.17-1
References for Section 8.17 . . . . 8.17-2
8.18 PHOSPHATE ROCK PROCESSING 8.18-1
8.18.1 Process Description 8.18-1
8.18.2 Emissions and Controls 8.18-1
References for Section 8.18 . . . . 8.18-2
8.19 SAND AND GRAVEL PROCESSING 8.19-1
8.19.1 Process Description 8.19-1
8.19.2 Emissions 8.19-1
References for Section 8.19 . . . . 8.19-1
8.20 STONE QUARRYING AND PROCESSING 8.20-1
8.20.1 Process Description 8.20-1
8.20.2 Emissions 8.20-1
References for Section 8.20 . . . . 8.20-2
9. PETROLEUM INDUSTRY 9.1-1
9.1 PETROLEUM REFINING 9.1-1
9.1.1 General 9.1-1

15<

CONTENTS–(Continued)

9.1.2 Crude Oil Distillation 9.1-1
    9.1.2.1 Emissions 9.1-1
9.1.3 Converting 9.1-6
    9.1.3.1 Catalytic Cracking 9.1-6
    9.1.3.2 Hydrocracking 9.1-6
    9.1.3.3 Catalytic Reforming 9.1-6
    9.1.3.4 Polymerization, Alkylation, and Isomerization 9.1-6
    9.1.3.5 Emissions 9.1-7
9.1.4 Treating 9.1-7
    9.1.4.1 Hydrogen Treating 9.1-7
    9.1.4.2 Chemical Treating 9.1-7
    9.1.4.3 Physical Treating 9.1-8
    9.1.4.4 Emissions 9.1-8
9.1.5 Blending 9.1-8
    9.1.5.1 Emissions 9.1-8
9.1.6 Miscellaneous Operations 9.1-8
References for Chapter 9 . . . . . 9.1-8
9.2 NATURAL GAS PROCESSING 9.2-1
9.2.1 General 9.2-1
9.2-2 Process Description 9.2-1
9.2-3 Emissions 9.2-1
References for Section 9.2 . . . . . 9.2-5
10. WOOD PROCESSING 10.1-1
10.1 CHEMICAL WOOD PULPING 10.1-1
10.1.1 General 10.1-1
10.1.2 Kraft Pulping 10.1-1
10.1.3 Acid Sulfite Pulping 10.1-4
    10.1.3.1 Process Description 10.1-4
    10.1.3.2 Emissions and Controls 10.1-7
10.1.4 Neutral Sulfite Semichemical (NSSC) Pulping 10.1-7
    10.1.4.1 Process Description 10.1-7
    10.1.4.2 Emissions and Controls 10.1-9
References for Section 10.1 . . . . . 10.1-9
10.2 PULPBOARD 10.2-1
10.2.1 General 10.2-1
10.2.2 Process Description 10.2-1
10.2.3 Emissions 10.2-1
References for Section 10.2 . . . . . 10.2-1
10.3 PLYWOOD VENEER AND LAYOUT OPERATIONS 10.3-1
10.3.1 Process Descriptions 10.3-1
10.3.2 Emissions 10.3-2
References for Section 10.3 . . . . . 10.3-2
10.4 WOODWORKING OPERATIONS 10.4-1
10.4.1 General 10.4-1
10.4.2 Emissions 10.4-1
References for Section 10.4 . . . . . 10.4-2
11. MISCELLANEOUS SOURCES 11.1-1
11.1 FOREST WILDFIRES 11.1-1
11.1.1 General 11.1-1
11.1.2 Emissions and Controls 11.1-2

16<

CONTENTS – (Continued)

Page

11.2 FUGITIVE DUST SOURCES 11.2-1
  11.2.1 Unpaved Roads (Dirt and Gravel) 11.2-1
  11.2.2 Agricultural Tilling 11.2.2-1
  11.2.3 Aggregate Storage Piles 11.2.3-1
  11.2.4 Heavy Construction Operations 11.2.4-1
APPENDIX A. MISCELLANEOUS DATA A-1
APPENDIX B. EMISSION FACTORS AND NEW SOURCE PERFORMANCE STANDARDS FOR STATIONARY SOURCES B-1
APPENDIX C. NEDS SOURCE CLASSIFICATION CODES AND EMISSION FACTOR LISTING C-1
APPENDIX D. PROJECTED EMISSION FACTORS FOR HIGHWAY VEHICLES D-1

17<

LIST OF TABLES

Table Page

1.1-1 Range of Collection Efficiencies for Common Types of Fly-Ash Control Equipment 1.1-2
1.1-2 Emission Factors for Bituminous Coal Combustion without Control Equipment 1.1-3
1.2-1 Emission Factors for Anthracite Combustion, Before Controls 1.2-3
1.3-1 Emission Factors for Fuel Oil Combustion 1.3-2
1.4-1 Emission Factors for Natural-Gas Combustion 1.4-2
1.5-1 Emission Factors for LPG Combustion 1.5-2
1.6-1 Emission Factors for Wood and Bark Combustion in Boilers with No Reinjection 1.6-2
1.7-1 Emissions from Lignite Combustion without Control Equipment 1.7-2
1.8-1 Emission Factors for Uncontrolled Bagasse Boilers 1.8-2
1.9-1 Emission Factors for Residential Fireplaces 1.9-2
2.1-1 Emission Factors for Refuse Incinerators without Controls 2.1-3
2.1-2 Collection Efficiencies for Various Types of Municipal Incineration Particulate Control Systems . . 2.1-4
2.2-1 Emission Factors for Auto Body Incineration 2.2-1
2.3-1 Emission Factors for Waste Incineration in Conical Burners without Controls 2.3-2
2.4-1 Emission Factors for Open Burning of Nonagricultural Material 2.4-1
2.4-2 Emission Factors and Fuel Loading Factors for Open Burning of Agricultural Materials 2.4-2
2.4-3 Emission Factors for Leaf Burning 2.4-4
2.5-1 Emission Factors for Sewage Sludge Incinerators 2.5-2
3.1.1-1 Average Emission Factors for Highway Vehicles, Calendar Year 1972 . . . . 3.1.1-4
3.1.2-1 Carbon Monoxide, Hydrocarbon, and Nitrogen Oxides Exhaust Emission Factors for Light-Duty Vehicles–Excluding California–for Calendar Year 1971 . . . . 3.1.2-2
3.1.2-2 Carbon Monoxide, Hydrocarbon, and Nitrogen Oxides Exhaust Emission Factors for Light-Duty Vehicles–State of California Only–for Calendar Year 1971 . . . . 3.1.2-3
3.1.2-3 Carbon Monoxide, Hydrocarbon, and Nitrogen Oxides Exhaust Emission Factors for Light-Duty Vehicles–Excluding California–for Calendar Year 1972 . . . . 3.1.2-3
3.1.2-4 Carbon Monoxide, Hydrocarbon, and Nitrogen Oxides Exhaust Emission Factors for Light-Duty Vehicles–State of California Only–for Calendar Year 1972 . . . . 3.1.2-4
3.1.2-5 Sample Calculation of Fraction of Light-Duty Vehicle Annual Travel by Model Year 3.1.2-4
3.1.2-6 Coefficients for Speed Correction Factors for Light-Duty Vehicles 3.1.2-5
3.1.2-7 Low Average Speed Correction Factors for Light-Duty Vehicles 3.1.2-6
3.1.2-8 Light-Duty Vehicle Temperature Correction Factors and Hot/Cold Vehicle Operation Correction Factors for FTP Emission Factors 3.1.2-6
3.1.2-9 Light-Duty Vehicle Modal Emission Model Correction Factors for Temperature and Cold/Hot Start Weighting 3.1.2-10
3.1.2-10 Carbon Monoxide, Hydrocarbon, and Nitrogen Oxides Emission Factors for Light-Duty Vehicles in Warmed-up Idle Mode 3.1.2-11
3.1.2-11 Crankcase Hydrocarbon Emissions by Model Year for Light-Duty Vehicles 3.1.2-12
3.1.2-12 Hydrocarbon Emission Factors by Model Year for Light-Duty Vehicles 3.1.2-13
3.1.2-13 Particulate and Sulfur Oxides Emission Factors for Light-Duty Vehicles 3.1.2-14
3.1.3-1 Emission Factors for Light-Duty, Diesel-Powered Vehicles 3.1.3-1
3.1.4-1 Exhaust Emission Factors for Light-Duty, Gasoline-Powered Trucks for Calendar Year 1972 . . . . 3.1.4-2
3.1.4-2 Coefficients for Speed Adjustment Curves for Light-Duty Trucks 3.1.4-2
3.1.4-3 Low Average Speed Correction Factors for Light-Duty Trucks 3.1.4-3
3.1.4-4 Sample Calculation of Fraction of Annual Light-Duty Truck Travel by Model Year 3.1.4-3
3.1.4-5 Light-Duty Truck Temperature Correction Factors and Hot/Cold Vehicle Operation Correction Factors for FTP Emission Factors 3.1.4-4
3.1.4-6 Crankcase and Evaporative Hydrocarbon Emission Factors for Light-Duty, Gasoline-Powered Trucks 3.1.4-6

18<

LIST OF TABLES–(Continued)

Table Page

3.1.4-7 Particulate and Sulfur Oxides Emission Factors Light-Duty, Gasoline-Powered Trucks 3.1.4-6
3.1.4-8 Exhaust Emission Factors for Heavy-Duty, Gasoline-Powered Trucks for Calendar Year 1972 3.1.4-7
3.1.4-9 Sample Calculation of Fraction of Gasoline-Powered, Heavy-Duty Vehicle Annual Travel by Model Year 3.1.4-8
3.1.4-10 Speed Correction Factors for Heavy-Duty Vehicles 3.1.4-9
3.1.4-11 Low Average Speed Correction Factors for Heavy-Duty Vehicles 3.1.4-10
3.1.4-12 Crankcase and Evaporative Hydrocarbon Emission Factors for Heavy-Duty, Gasoline-Powered Vehicles 3.1.4-10
3.1.4-13 Particulate and Sulfur Oxides Emission Factors for Heavy-Duty Gasoline-Powered Vehicles 3.1.4-11
3.1.5-1 Emission Factors for Heavy-Duty, Diesel-Powered Vehicles (All Pre-1973 Model Years) for Calendar Year 1972 3.1.5-2
3.1.5-2 Emission Factors for Heavy-Duty, Diesel-Powered Vehicles under Different Operating Conditions 3.1.5-3
3.1.6-1 Emission Factors by Model Year for Light-Duty Vehicles Using LPG, LPG/Dual Fuel, or CNG/Dual Fuel 3.1.6-2
3.1.6-2 Emission Factors for Heavy-Duty Vehicles Using LPG or CNG/Duel Fuel 3.1.6-2
3.1.7-1 Emission Factors for Motorcycles 3.1.7-2
3.2.1-1 Aircraft Classification 3.2.1-2
3.2.1-2 Typical Time in Mode for Landing-Takeoff Cycle 3.2.1-3
3.2.1-3 Emission Factors per Aircraft Landing-Takeoff Cycle 3.2.1-4
3.2.1-4 Modal Emission Factors 3.2.1-6
3.2.2-1 Average Locomotive Emission Factors Based on Nationwide Statistics 3.2.2-1
3.2.2-2 Emission Factors by Locomotive Engine Category 3.2.2-2
3.2.3-1 Average Emission Factors for Commercial Motorships by Waterway Classification 3.2.3-2
3.2.3-2 Emission Factors for Commercial Steamships– All Geographic Areas 3.2.3-3
3.2.3-3 Diesel Vessel Emission Factors by Operating Mode 3.2.3-4
3.2.3-4 Average Emission Factors for Diesel-Powered Electrical Generators in Vessels 3.2.3-5
3.2.3-5 Average Emission Factors for Inboard Pleasure Craft 3.2.3-6
3.2.4-1 Average Emission Factors for Outboard Motors 3.2.4-1
3.2.5-1 Emission Factors for Small, General Utility Engines 3.2.5-2
3.2.6-1 Service Characteristics of Farm Equipment (Other than Tractors) 3.2.6-1
3.2.6-2 Emission Factors for Wheeled Farm Tractors and Non-Tractor Agricultural Equipment 3.2.6-2
3.2.7-1 Emission Factors for Heavy-Duty, Diesel-Powered Construction Equipment 3.2.7-2
3.2.7-2 Emission Factors for Heavy-Duty, Gasoline-Powered Construction Equipment 3.2.7-4
3.2.8-1 Emission Factors for Snowmobiles 3.2.8-2
3.3.1-1 Typical Operating Cycle for Electric Utility Turbines 3.3.1-2
3.3.1-2 Composite Emission Factors for 1971 Population of Electric Utility Turbines 3.3.1-2
3.3.2-1 Emission Factors for Heavy-Duty, Natural-Gas-Fired Pipeline Compressor Engines 3.3.2-2
3.3.3-1 Emission Factors for Gasoline- and Diesel-Powered Industrial Equipment 3.3.3-1
4.1-1 Solvent Loss Emission Factors for Dry Cleaning Operations 4.1-4
4.2-1 Gaseous Hydrocarbon Emission Factors for Surface-Coating Applications 4.2-1
4.3-1 Physical Properties of Hydrocarbons 4.3-7
4.3-2 Paint Factors for Fixed Roof Tanks 4.3-10
4.3-3 Tank, Type, Seal, and Paint Factors for Floating Roof Tanks 4.3-13
4.3-4 Evaporative Emission Factors for Storage Tanks 4.3-15
4.4-1 S Factors for Calculating Petroleum Loading Losses 4.4-6
4.4-2 Hydrocarbon Emission Factors for Gasoline Loading Operations 4.4-7
4.4-3 Hydrocarbon Emission Factors for Petroleum Liquid Transportation and Marketing Sources 4.4-8
4.4-4 Hydrocarbon Emissions from Gasoline Service Station Operations 4.4-11
5.1-1 Emission Factors for Adipic Acid Manufacture 5.1-4

19<

LIST OF TABLES—(Continued)

Table Page

5.2-1 Emission Factors for Ammonia Manufacturing without Control Equipment 5.2-2
5.3-1 Emission Factors for Carbon Black Manufacturing 5.3-4
5.4-1 Emission Factors for Charcoal Manufacturing 5.4-1
5.5-1 Emission Factors for Chlor-Alkali Plants 5.5-2
5.6-1 Emission Factors for Explosives Manufacturing 5.6-4
5.7-1 Emission Factors for Hydrochloric Acid Manufacturing 5.7-1
5.8-1 Emission Factors for Hydrofluoric Acid Manufacturing 5.8-1
5.9-1 Nitrogen Oxide Emissions from Nitric Acid Plants 5.9-3
5.10-1 Emission Factors for Paint and Varnish Manufacturing without Control Equipment 5.10-2
5.11-1 Emission Factors for Phosphoric Acid Production 5.11-2
5.12-1 Emission Factors for Phthalic Anhydride 5.12-5
5.13-1 Emission Factors for Plastics Manufacturing without Controls 5.13-1
5.14-1 Emission Factors for Printing Ink Manufacturing 5.14-2
5.15-1 Particulate Emission Factors for Spray-Drying Detergents 5.15-1
5.16-1 Emission Factors for Soda-Ash Plants without Control 5.16-1
5.17-1 Emission Factors for Sulfuric Acid Plants 5.17-5
5.17-2 Acid Mist Emission Factors for Sulfuric Acid Plants without Controls 5.17-7
5.17-3 Collection Efficiency and Emissions Comparison of Typical Electrostatic Precipitator and Fiber Mist Eliminator 5.17-8
5.18-1 Emission Factors for Modified Claus Sulfur Plants 5.18-2
5.19-1 Emission Factors for Synthetic Fibers Manufacturing 5.19-1
5.20-1 Emission Factors for Synthetic Rubber Plants: Butadiene-Acrylonitrile and Butadiene-Styrene . 5.20-1
5.21-1 Nitrogen Oxides Emission Factors for Terephthalic Acid Plants 5.21-1
6.1-1 Particulate Emission Factors for Alfalfa Dehydrating Plants 6.1-2
6.2-1 Emission Factors for Coffee Roasting Processes without Controls 6.2-1
6.3-1 Emission Factors for Cotton Ginning Operations without Controls 6.3-1
6.4-1 Particulate Emission Factors for Uncontrolled Grain Elevators 6.4-2
6.4-2 Particulate Emission Factors for Grain Elevators Based on Amount of Grain Received or Shipped 6.4-3
6.4-3 Particulate Emission Factors for Grain Processing Operations 6.4-4
6.5-1 Emission Factors for Fermentation Processes 6.5-2
6.6-1 Emission Factors for Fish Processing Plants 6.6-3
6.7-1 Emission Factors for Meat Smoking 6.7-1
6.8-1 Emission Factors for Nitrate Fertilizer Manufacturing without Controls 6.8-2
6.9-1 Emission Factors for Orchard Heaters 6.9-4
6.10-1 Emission Factors for Production of Phosphate Fertilizers 6.10-1
6.11-1 Emission Factors for Starch Manufacturing 6.11-1
7.1-1 Raw Material and Energy Requirements for Aluminum Production 7.1-2
7.1-2 Representative Particle Size Distributions of Uncontrolled Effluents from Prebake and Horizontal-Stud Soderberg Cells 7.1-4
7.1-3 Emission Factors for Primary Aluminum Production Processes 7.1-5
7.2-1 Emission Factors for Metallurgical Coke Manufacture without Controls 7.2-2
7.3-1 Emission Factors for Primary Copper Smelters without Controls 7.3-2
7.4-1 Emission Factors for Ferroalloy Production in Electric Smelting Furnaces 7.4-2
7.5-1 Emission Factors for Iron and Steel Mills 7.5-4
7.6-1 Emission Factors for Primary Lead Smelting Processes without Controls 7.6-4
7.6-2 Efficiencies of Representative Control Devices Used with Primary Lead Smelting Operations . . 7.6-5
7.7-1 Emission Factors for Primary Zinc Smelting without Controls 7.7-1
7.8-1 Particulate Emission Factors for Secondary Aluminum Operations 7.8-1
7.9-1 Particulate Emission Factors for Brass and Bronze Melting Furnaces without Controls 7.9-2
7.10-1 Emission Factors for Gray Iron Foundries 7.10-1
7.11-1 Emission Factors for Secondary Lead Smelting Furnaces without Controls 7.11-2

LIST OF TABLES--(Continued)

Table Page

7.11-2 Efficiencies of Particulate Control Equipment Associated with Secondary Lead Smelting Furnaces 7.11-3
7.11-3 Representative Particle Size Distribution from Combined Blast and Reverberatory Furnace Gas Stream 7.11-3
7.12-1 Emission Factors for Magnesium Smelting 7.12-1
7.13-1 Emission Factors for Steel Foundries 7.13-2
7.14-1 Particulate Emission Factors for Secondary Zinc Smelting 7.14-2
8.1-1 Particulate Emission Factors for Asphaltic Concrete Plants 8.1-4
8.2-1 Emission Factors for Asphalt Roofing Manufacturing without Controls 8.2-1
8.3-1 Emission Factors for Brick Manufacturing without Controls 8.3-3
8.4-1 Emission Factors for Calcium Carbide Plants 8.4-1
8.5-1 Particulate Emission Factors for Castable Refractories Manufacturing 8.5-1
8.6-1 Emission Factors for Cement Manufacturing without Controls 8.6-3
8.6-2 Size Distribution of Dust Emitted from Kiln Operations without Controls 8.6-4
8.7-1 Particulate Emission Factors for Ceramic Clay Manufacturing 8.7-1
8.8-1 Particulate Emission Factors for Sintering Operations 8.8-2
8.9-1 Particulate Emission Factors for Thermal Coal Dryers 8.9-1
8.10-1 Particulate Emission Factors for Concrete Batching 8.10-1
8.11-1 Emission Factors for Fiber Glass Manufacturing without Controls 8.11-3
8.12-1 Emission Factors for Frit Smelters without Controls 8.12-2
8.13-1 Emission Factors for Glass Melting 8.13-1
8.14-1 Particulate Emission Factors for Gypsum Processing 8.14-1
8.15-1 **Emission Factors for Lime Manufacturing** **8.15-4**
8.16-1 Emission Factors for Mineral Wool Processing without Controls 8.16-2
8.17-1 Particulate Emission Factors for Perlite Expansion Furnaces without Controls 8.17-1
8.18-1 Particulate Emission Factors for Phosphate Rock Processing without Controls 8.18-1
8.20-1 Particulate Emission Factors for Rock-Handling Processes 8.20-1
9.1-1 Emission Factors for Petroleum Refineries 9.1-3
9.2-1 **Emission Factors for Gas Sweetening Plants** **9.2-3**
9.2-2 **Average Hydrogen Sulfide Concentrations in Natural Gas by Air Quality Control Region** **9.2-4**
10.1.2-1 Emission Factors for Sulfate Pulping 10.1-5
10.1.3-1 **Emission Factors for Sulfite Pulping** **10.1-8**
10.2-1 Particulate Emission Factors for Pulpboard Manufacturing 10.2-1
10.3-1 Emission Factors for Plywood Manufacturing 10.3-1
10.4-1 **Particulate Emission Factors for Large Diameter Cyclones in Woodworking Industry** **10.4-2**
11.1-1 Summary of Estimated Fuel Consumed by Forest Fires 11.1-2
11.1-2 Summary of Emissions and Emission Factors for Forest Wildfires 11.1-4
11.2.1-1 Control Methods for Unpaved Roads 11.2-4
11.2.3-1 Aggregate Storage Emissions 11.2.3-1
A-1 Nationwide Emissions for 1971 . . . . . A-2
A-2 Distribution by Particle Size of Average Collection Efficiencies for Various Particulate Control Equipment A-3
A-3 Thermal Equivalents for Various Fuels A-4
A-4 Weights of Selected Substances A-4
A-5 General Conversion Factors A-5
B-1 Promulgated New Source Performance Standards B-2
B-2 Promulgated New Source Performance Standards B-4

LIST OF FIGURES

Figure — Page

1.4-1 Lead Reduction Coefficient as Function of Boiler Load . . . 1.4-2
3.3.2-1 Nitrogen Oxide Emissions from Stationary Internal Combustion Engines . . . 3.3.2-2
4.1-1 Percloroethylene Dry Cleaning Plant Flow Diagram . . . 4.1-2
4.3-1 Flowsheet of Petroleum Production, Refining, and Distribution Systems . . . 4.3-2
4.3-2 Fixed Roof Storage Tank . . . 4.3-3
4.3-3 Pan Type Floating Roof Storage Tank . . . 4.3-3
4.3-4 Double Deck Floating Roof Storage Tank . . . 4.3-3
4.3-5 Covered Floating Roof Storage Tank . . . 4.3-4
4.3-6 Lifter Roof Storage Tank . . . 4.3-4
4.3-7 Flexible Diaphragm Tank . . . 4.3-5
4.3-8 Vapor Pressures of Gasolines and Finished Petroleum Products . . . 4.3-8
4.3-9 Vapor Pressures of Crude Oil . . . 4.3-9
4.3-10 Adjustment Factor (C) for Small Diameter Tanks . . . 4.3-10
4.3-11 Turnover Factor (K_N) for Fixed Roof Tanks . . . 4.3-11
4.4-1 Flowsheet of Petroleum Production, Refining, and Distribution Systems . . . 4.4-2
4.4-2 Splash Loading Method . . . 4.4-3
4.4-3 Submerged Fill Pipe . . . 4.4-3
4.4-4 Bottom Loading . . . 4.4-4
4.4-5 Tanktruck Unloading Into an Underground Service Station Storage Tank . . . 4.4-5
4.4-6 Tanktruck Loading with Vapor Recovery . . . 4.4-9
4.4-7 Automobile Refueling Vapor Recovery System . . . 4.4-12
5.1-1 General Flow Diagram of Adipic Acid Manufacturing Process . . . 5.1-3
5.3-1 Simplified Flow Diagram of Carbon Black Production by the Oil-Fired Furnace Process . . . 5.3-2
5.6-1 Flow Diagram of Typical Batch Process TNT Plant . . . 5.6-2
5.9-1 Flow Diagram of Typical Nitric Acid Plant Using Pressure Process . . . 5.9-2
5.12-1 Flow Diagram for Phthalic Anhydride using O-Xylene as Basic Feedstock . . . 5.12-3
5.12-2 Flow Diagram for Phthalic Anhydride using Naphthalene as Basic Feedstock . . . 5.12-4
5.17-1 Basic Flow Diagram of Contact-Process Sulfuric Acid Plant Burning Elemental Sulfur . . . 5.17-2
5.17-2 Basic Flow Diagram of Contact-Process Sulfuric Acid Plant Burning Spent Acid . . . 5.17-3
5.17-3 Sulfuric Acid Plant Feedstock Sulfur Conversion Versus Volumetric and Mass SO_2 Emissions at Various Inlet SO_2 Concentrations by Volume . . . 5.17-6
5.18-1 Basic Flow Diagram of Modified Claus Process with Two Converter Stages Used in Manufacturing Sulfur . . . 5.18-2
6.1-1 Generalized Flow Diagram for Alfalfa Dehydration Plant . . . 6.1-3
6.6-1 A Generalized Fish Processing Flow Diagram . . . 6.6-2
6.9-1 Types of Orchard Heaters . . . 6.9-2
6.9-2 Particulate Emissions from Orchard Heaters . . . 6.9-3
7.1-1 Schematic Diagram of Primary Aluminum Production Process . . . 7.1-3
7.5-1 Basic Flow Diagram of Iron and Steel Processes . . . 7.5-2
7.6-1 Typical Flowsheet of Pyrometallurgical Lead Smelting . . . 7.6-2
7.11-1 Secondary Lead Smelter Processes . . . 7.11-2
8.1-1 Batch Hot-Mix Asphalt Plant . . . 8.1-2
8.1-2 Continuous Hot-Mix Asphalt Plant . . . 8.1-3
8.3-1 Basic Flow Diagram of Brick Manufacturing Process . . . 8.3-2
8.6-1 Basic Flow Diagram of Portland Cement Manufacturing Process . . . 8.6-2
8.11-1 Typical Flow Diagram of Textile-Type Glass Fiber Production Process . . . 8.11-2
8.11-2 Typical Flow Diagram of Wool-Type Glass Fiber Production Process . . . 8.11-2
8.15-1 Generalized Lime Manufacturing Plant . . . 8.15-2
9.1-1 Basic Flow Diagram of Petroleum Refinery . . . 9.1-2
9.2-1 Generalized Flow Diagram of the Natural Gas Industry . . . 9.2-2

22<

LIST OF FIGURES– (Continued)

Figure . . . Page

9.2-2 Flow Diagram of the Amine Process Gas Sweetening 9.2-3
10.1.2-1 Typical Kraft Sulfate Pulping and Recovery Process 10.1-2
10.1.3-1 Simplified Process Flow Diagram of Magnesium-Base Process Employing Chemical and Heat Recovery 10.1-6
11.1-1 Forest Areas and U.S. Forest Service Regions 11.1-3
11.2-1 Mean Number of Days with 0.01 inch or more of Annual Precipitation in United States 11.2-3
11.2-2 Map of Thornthwaites Precipitation-Evaporation Index Values for State Climatic Divisions 11.2.2-3
B-2 Promulgated New Source Performance Standards B-1

23<

ABSTRACT

Emission data obtained from source tests, material balance studies, engineering estimates, etc., have been compiled for use by individuals and groups responsible for conducting air pollution emission inventories. Emission factors given in this document, the result of the expansion and continuation of earlier work, cover most of the common emission categories: fuel combustion by stationary and mobile sources; combustion of solid wastes; evaporation of fuels, solvents, and other volatile substances; various industrial processes; and miscellaneous sources. When no source-test data are available, these factors can be used to estimate the quantities of primary pollutants (particulates, CO, SO_2, NO_x, and hydrocarbons) being released from a source or source group.

Key words: fuel combustion, stationary sources, mobile sources, industrial processes, evaporative losses, emissions, emission data, emission inventories, primary pollutants, emission factors.

1. EXTERNAL COMBUSTION SOURCES

External combustion sources include steam-electric generating plants, industrial boilers, commercial and institutional boilers, and commercial and domestic combustion units. Coal, fuel oil, and natural gas are the major fossil fuels used by these sources. Other fuels used in relatively small quantities are liquefied petroleum gas, wood, coke, refinery gas, blast furnace gas, and other waste- or by-product fuels. Coal, oil, and natural gas currently supply about 95 percent of the total thermal energy consumed in the United States. In 1970 over 500 million tons (454×10^6 MT) of coal, 623 million barrels (99×10^9 liters) of distillate fuel oil, 715 million barrels (114×10^9 liters) of residual fuel oil, and 22 trillion cubic feet (623×10^{12} liters) of natural gas were consumed in the United States.[1]

Power generation, process heating, and space heating are some of the largest fuel-combustion sources of sulfur oxides, nitrogen oxides, and particulate emissions. The following sections present emission factor data for the major fossil fuels – coal, fuel oil, and natural gas – as well as for liquefied petroleum gas and wood waste combustion in boilers.

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1.1 BITUMINOUS COAL COMBUSTION

Revised by Robert Rosensteel
and Thomas Lahre

1.1.1 General

Coal, the most abundant fossil fuel in the United States, is burned in a wide variety of furnaces to produce heat and steam. Coal-fired furnaces range in size from small handfired units with capacities of 10 to 20 pounds (4.5 to 9 kilograms) of coal per hour to large pulverized-coal-fired units, which may burn 300 to 400 tons (275 to 360 MT) of coal per hour.

Although predominantly carbon, coal contains many compounds in varying amounts. The exact nature and quantity of these compounds are determined by the location of the mine producing the coal and will usually affect the final use of the coal.

1.1.2 Emissions and Controls

1.1.2.1 Particulates[1] - Particulates emitted from coal combustion consist primarily of carbon, silica, alumina, and iron oxide in the fly-ash. The quantity of atmospheric particulate emissions is dependent upon the type of combustion unit in which the coal is burned, the ash content of the coal, and the type of control equipment used.

Table 1.1-1 gives the range of collection efficiencies for common types of fly-ash control equipment. Particulate emission factors expressed as pounds of particulate per ton of coal burned are presented in Table 1.1-2.

1.1.2.2 Sulfur Oxides[11] - Factors for uncontrolled sulfur oxides emission are shown in Table 1-2 along with factors for other gases emitted. The emission factor for sulfur oxides indicates a conversion of 95 percent of the available sulfur to sulfur oxide. The balance of the sulfur is emitted in the fly-ash or combines with the slag or ash in the furnace and is removed with them.[1] Increased attention has been given to the control of sulfur oxide emissions from the combustion of coal. The use of low-sulfur coal has been recommended in many areas; where low-sulfur coal is not available, other methods in which the focus is on the removal of sulfur oxide from the flue gas before it enters the atmosphere must be given consideration.

A number of flue-gas desulfurization processes have been evaluated; effective methods are undergoing full-scale operation. Processes included in this category are: limestone-dolomite injection, limestone wet scrubbing, catalytic oxidation, magnesium oxide scrubbing, and the Wellman-Lord process. Detailed discussion of various flue-gas desulfurization processes may be found in the literature.[12,13]

1.1.2.3. Nitrogen Oxides[1,5] - Emissions of oxides of nitrogen result not only from the high temperature reaction of atmospheric nitrogen and oxygen in the combustion zone, but also from the partial combustion of nitrogenous compounds contained in the fuel. The important factors that affect NO_x production are: flame and furnace temperature, residence time of combustion gases at the flame temperature, rate of cooling of the gases, and amount of excess air present in the flame. Discussions of the mechanisms involved are contained in the indicated references.

1.1.2.4 Other Gases - The efficiency of combustion primarily determines the carbon monoxide and hydrocarbon content of the gases emitted from bituminous coal combustion. Successful combustion that results in a low level of carbon monoxide and organic emissions requires a high degree of turbulence, a high temperature, and sufficient time for the combustion reaction to take place. Thus, careful control of excess air rates, the use of high combustion temperature, and provision for intimate fuel-air contact will minimize these emissions.

Factors for these gaseous emissions are also presented in Table 1.1-2. The size range in Btu per hour for the various types of furnaces as shown in Table 1.1-2 is only provided as a guide in selecting the proper factor and is not meant to distinguish clearly between furnace applications.

TABLE 1.1-1. RANGE OF COLLECTION EFFICIENCIES FOR COMMON TYPES OF FLY-ASH CONTROL EQUIPMENT[a]

	Range of collection efficiencies, %			
Type of furnace	Electrostatic precipitator	High-efficiency cyclone	Low-resistance cyclone	Settling chamber expanded chimney bases
Cyclone furnace	65 to 99.5[b]	30 to 40	20 to 30	10[b]
Pulverized unit	80 to 99.5[b]	65 to 75	40 to 60	20[b]
Spreader stoker	99.5[b]	85 to 90	70 to 80	20 to 30
Other stokers	99.5[b]	90 to 95	75 to 85	25 to 50

[a] References 1 and 2.

[b] The maximum efficiency to be expected for this collection device applied to this type source.

Table 1.1-2. EMISSION FACTORS FOR BITUMINOUS COAL COMBUSTION WITHOUT CONTROL EQUIPMENT EMISSION FACTOR RATING: A

Furnace size, 10⁶ Btu/hr heat input[a]	Particulates[b]		Sulfur oxides[c]		Carbon monoxide		Hydrocarbons[d]		Nitrogen oxides		Aldehydes	
	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned
Greater than 100[e] (Utility and large industrial boilers)												
Pulverized												
General	16A	8A	38S	19S	1	0.5	0.3	0.15	18	9	0.005	0.0025
Wet bottom	13A[f]	6.5A	38S	19S	1	0.5	0.3	0.15	30	15	0.005	0.0025
Dry bottom	17A	8.5A	38S	19S	1	0.5	0.3	0.15	18	9	0.005	0.0025
Cyclone	2A	1A	38S	19S	1	0.5	0.3	0.15	55	27.5	0.005	0.0025
10 to 100[g] (large commercial and general industrial boilers)												
Spreader stoker[h]	13A[i]	6.5A	38S	19S	2	1	1	0.5	15	7.5	0.005	0.0025
Less than 10[j] (commercial and domestic furnaces)												
Underfeed stoker	2A	1A	38S	19S	10	5	3	1.5	6	3	0.005	0.0025
Hand-fired units	20	10	38S	19S	90	45	20	10	3	1.5	0.005	0.0025

[a] 1 Btu/hr = 0.252 kcal/hr.

[b] The letter A on all units other than hand-fired equipment indicates that the weight percentage of ash in the coal should be multiplied by the value given. Example: If the factor is 16 and the ash content is 10 percent, the particulate emissions before the control equipment would be 10 times 16, or 160 pounds of particulate per ton of coal (10 times 8, or 80 kg of particulates per MT of coal).

[c] S equals the sulfur content (see footnote b above).

[d] Expressed as methane.

[e] References 1 and 3 through 7.

[f] Without fly-ash reinjection.

[g] References 1, 4, and 7 through 9.

[h] For all other stokers use 5A for particulate emission factor.

[i] Without fly-ash reinjection. With fly-ash reinjection use 20 A. This value is not an emission factor but represents loading reaching the control equipment.[1]

[j] References 7, 9, and 10.

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1.2 ANTHRACITE COAL COMBUSTION

revised by Tom Lahre

1.2.1 General[1,2]

Anthracite is a high-rank coal having a high fixed-carbon content and low volatile-matter content relative to bituminous coal and lignite. It is also characterized by higher ignition and ash fusion temperatures. Because of its low volatile-matter content and non-clinkering characteristics, anthracite is most commonly fired in medium-sized traveling-grate stokers and small hand-fired units. Some anthracite (occasionally along with petroleum coke) is fired in pulverized-coal-fired boilers. None is fired in spreader stokers. Because of its low sulfur content (typically less than 0.8 percent, by weight) and minimal smoking tendencies, anthracite is considered a desirable fuel where readily available.

In the United States, all anthracite is mined in Northeastern Pennsylvania and consumed primarily in Pennsylvania and several surrounding states. The largest use of anthracite is for space heating; lesser amounts are employed for steam-electric production, coke manufacturing, sintering and pelletizing, and other industrial uses. Anthracite combustion currently represents only a small fraction of the total quantity of coal combusted in the United States.

1.2.2 Emissions and Controls[2-9]

Particulate emissions from anthracite combustion are a function of furnace-firing configuration, firing practices (boiler load, quantity and location of underfire air, sootblowing, flyash reinjection, etc.), as well as of the ash content of the coal. Pulverized-coal-fired boilers emit the highest quantity of particulate per unit of fuel because they fire the anthracite in suspension, which results in a high percentage of ash carryover into the exhaust gases. Traveling-grate stokers and hand-fired units, on the other hand, produce much less particulate per unit of fuel fired. This is because combustion takes place in a quiescent fuel bed and does not result in significant ash carryover into the exhaust gases. In general, particulate emissions from traveling-grate stokers will increase during sootblowing, flyash reinjection, and with higher underfeed air rates through the fuel bed. Higher underfeed air rates, in turn, result from higher grate loadings and the use of forced-draft fans rather than natural draft to supply combustion air. Smoking is rarely a problem because of anthracite's low volatile-matter content.

Limited data are available on the emission of gaseous pollutants from anthracite combustion. It is assumed, based on data derived from bituminous coal combustion, that a large fraction of the fuel sulfur is emitted as sulfur oxides. Moreover, because combustion equipment, excess air rates, combustion temperatures, etc., are similar between anthracite and bituminous coal combustion, nitrogen oxide and carbon monoxide emissions are assumed to be similar, as well. On the other hand, hydrocarbon emissions are expected to be considerably lower because the volatile-matter content of anthracite is significantly less than that of bituminous coal.

Air pollution control of emissions from anthracite combustion has mainly been limited to particulate matter. The most efficient particulate controls--fabric filters, scrubbers, and electrostatic precipitators--have been installed on large pulverized-anthracite-fired boilers. Fabric filters and venturi scrubbers can effect collection efficiencies exceeding 99 percent. Electrostatic precipitators, on the other hand, are typically only 90 to 97 percent efficient due to the characteristic high resistivity of the low-sulfur anthracite flyash. Higher efficiencies can reportedly be achieved using larger precipitators and flue gas conditioning. Mechanical collectors are frequently employed upstream from these devices for large-particle removal.

Traveling-grate stokers are often uncontrolled. Indeed, particulate control has often been considered unnecessary because of anthracite's low smoking tendencies and due to the fact that a significant fraction of the large-sized flyash from stokers is readily collected in flyash hoppers as well as in the breeching and base of the stack. Cyclone collectors have been employed on traveling-grate stokers;

limited information suggests these devices may be up to 75 percent efficient on particulate. Flyash reinjection, frequently employed in traveling-grate stokers to enhance fuel-use efficiency, tends to increase particulate emissions per unit of fuel combusted.

Emission factors for anthracite combustion are presented in Table 1.2-1.

30<

Table 1.2-1. EMISSION FACTORS FOR ANTHRACITE COMBUSTION, BEFORE CONTROLS
EMISSION FACTOR RATING: B

	Emissions[a]									
	Particulate		Sulfur oxides[b]		Hydrocarbons[c]		Carbon monoxide[d]		Nitrogen oxides[e]	
Type of furnace	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Pulverized coal	17A[f]	8.5A[f]	38S	19S	Neg	Neg	1	0.5	18	9
Traveling grate	1A[g]	0.5A[g]	38S	19S	Neg	Neg	1	0.5	10	5
Hand-fired	10[h]	5[h]	38S	19S	2.5	1.25	90	45	3	1.5

[a] All emission factors are per unit of anthracite fired.

[b] These factors are based on the assumption that, as with bituminous coal combustion, most of the fuel sulfur is emitted as sulfur oxides. Limited data in Reference 5 verify this assumption for pulverized-anthracite-fired boilers. Generally most of these emissions are sulfur dioxide; however, approximately 1 to 3 percent are sulfur trioxide.

[c] Hydrocarbon emissions from anthracite combustion are assumed to be lower than from bituminous coal combustion because of anthracite's much lower volatile-matter content. No emissions data are available to verify this assumption.

[d] The carbon monoxide factors for pulverized-anthracite-fired boilers and hand-fired units are from Table 1.1-2.and are based on the similarity between anthracite and bituminous coal combustion. The pulverized-coal-fired boilers factor is substantiated by additional data in Reference 10. The factor for traveling-grate stokers is based on limited information in Reference 8. Carbon monoxide emissions may increase by several orders of magnitude if a boiler is not properly operated or well maintained.

[e] The nitrogen oxide factors for pulverized-anthracite-fired boilers and hand-fired units are assumed to be similar to those for bituminous coal combustion given in Table 1.1-2. The factors for traveling-grate stokers are based on Reference 8.

[f] These factors are based on the similarity between anthracite and bituminous coal combustion and on limited data in Reference 5. Note that all pulverized-anthracite-fired boilers operate in the dry tap or dry bottom mode due to anthracite's characteristically high ash-fusion temperature. The letter A on units other than hand-fired equipment indicates that the weight percentage of ash in the coal should be multiplied by the value given.

[g] Based on information in References 2,4,8, and 9. These factors account for limited fallout that may occur in fallout chambers and stack breeching. Emission factors for individual boilers may vary from 0.5A lb/ton (0.25A kg/MT) to 3A lb/ton (1.5A kg/MT), and as high as 5A lb/ton (2.5A kg/MT) during soot blowing.

[h] Based on limited information in Reference 2.

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1.3 FUEL OIL COMBUSTION

by Tom Lahre

1.3.1 General[1,2]

Fuel oils are broadly classified into two major types: distillate and residual. Distillate oils (fuel oil grades 1 and 2) are used mainly in domestic and small commercial applications in which easy fuel burning is required. Distillates are more volatile and less viscous than residual oils as well as cleaner, having negligible ash and nitrogen contents and usually containing less than 0.3 percent sulfur (by weight). Residual oils (fuel oil grades 4, 5, and 6), on the other hand, are used mainly in utility, industrial, and large commercial applications in which sophisticated combustion equipment can be utilized. (Grade 4 oil is sometimes classified as a distillate; grade 6 is sometimes referred to as Bunker C.) Being more viscous and less volatile than distillate oils, the heavier residual oils (grades 5 and 6) must be heated for ease of handling and to facilitate proper atomization. Because residual oils are produced from the residue left over after the lighter fractions (gasoline, kerosene, and distillate oils) have been removed from the crude oil, they contain significant quantities of ash, nitrogen, and sulfur. Properties of typical fuel oils are given in Appendix A.

1.3.2 Emissions

Emissions from fuel oil combustion are dependent on the grade and composition of the fuel, the type and size of the boiler, the firing and loading practices used, and the level of equipment maintenance. Table 1.3-1 presents emission factors for fuel oil combustion in units without control equipment. Note that the emission factors for industrial and commercial boilers are divided into distillate and residual oil categories because the combustion of each produces significantly different emissions of particulates, SO_x, and NO_x. The reader is urged to consult the references cited for a detailed discussion of all of the parameters that affect emissions from oil combustion.

1.3.2.1 Particulates[3-6, 12, 13] – Particulate emissions are most dependent on the grade of fuel fired. The lighter distillate oils result in significantly lower particulate formation than do the heavier residual oils. Among residual oils, grades 4 and 5 usually result in less particulate than does the heavier grade 6.

In boilers firing grade 6, particulate emissions can be described, on the average, as a function of the sulfur content of the oil. As shown in Table 1.3-1 (footnote c), particulate emissions can be reduced considerably when low-sulfur grade 6 oil is fired. This is because low-sulfur grade 6, whether refined from naturally occurring low-sulfur crude oil or desulfurized by one of several processes currently in practice, exhibits substantially lower viscosity and reduced asphaltene, ash, and sulfur content – all of which result in better atomization and cleaner combustion.

Boiler load can also affect particulate emissions in units firing grade 6 oil. At low load conditions, particulate emissions may be lowered by 30 to 40 percent from utility boilers and by as much as 60 percent from small industrial and commercial units. No significant particulate reductions have been noted at low loads from boilers firing any of the lighter grades, however. At too low a load condition, proper combustion conditions cannot be maintained and particulate emissions may increase drastically. It should be noted, in this regard, that any condition that prevents proper boiler operation can result in excessive particulate formation.

1.3.2.2 Sulfur Oxides (SO_x)[1-5] – Total sulfur oxide emissions are almost entirely dependent on the sulfur content of the fuel and are not affected by boiler size, burner design, or grade of fuel being fired. On the average, more than 95 percent of the fuel sulfur is converted to SO_2, with about 1 to 3 percent further oxidized to SO_3. Sulfur trioxide readily reacts with water vapor (both in the air and in the flue gases) to form a sulfuric acid mist.

Table 1.3-1. EMISSION FACTORS FOR FUEL OIL COMBUSTION
EMISSION FACTOR RATING: A

	Type of boiler[a]							
	Power plant		Industrial and commercial				Domestic	
	Residual oil		Residual oil		Distillate oil		Distillate oil	
Pollutant	lb/10^3 gal	kg/10^3 liter	lb/10^3 gal	kg/10^3 liter	lb/10^3 gal	kg/10^3 liter	lb/10^3 gal	kg/10^3 liter
Particulate[b]	c	c	c	c	2	0.25	2.5	0.31
Sulfur dioxide[d]	157S	19S	157S	19S	142S	17S	142S	17S
Sulfur trioxide[d]	2S	0.25S	2S	0.25S	2S	0.25S	2S	0.25S
Carbon monoxide[e]	5	0.63	5	0.63	5	0.63	5	0.63
Hydrocarbons (total, as CH_4)[f]	1	0.12	1	0.12	1	0.12	1	0.12
Nitrogen oxides (total, as NO_2)[g]	105(50)[h,i]	12.6(6.25)[h,i]	60[j]	7.5[j]	22	2.8	18	2.3

[a] Boilers can be classified, roughly, according to their gross (higher) heat input rate, as shown below.

Power plant (utility) boilers: $>250 \times 10^6$ Btu/hr
($>63 \times 10^6$ kg-cal/hr)

Industrial boilers: $>15 \times 10^6$, but $<250 \times 10^6$ Btu/hr
($>3.7 \times 10^6$, but $<63 \times 10^6$ kg-cal/hr)

Commercial boilers: $>0.5 \times 10^6$, but $<15 \times 10^6$ Btu/hr
($>0.13 \times 10^6$, but $<3.7 \times 10^6$ kg-cal/hr)

Domestic (residential) boilers: $<0.5 \times 10^6$ Btu/hr
($<0.13 \times 10^6$ kg-cal/hr)

[b] Based on References 3 through 6. Particulate is defined in this section as that material collected by EPA Method 5 (front half catch)[7].

[c] Particulate emission factors for residual oil combustion are best described, on the average, as a function of fuel oil grade and sulfur content, as shown below.

Grade 6 oil: lb/10^3 gal = 10 (S) + 3
[kg/10^3 liter = 1.25 (S) + 0.38]
Where: S is the percentage, by weight, of sulfur in the oil

Grade 5 oil: 10 lb/10^3 gal (1.25 kg/10^3 liter)

Grade 4 oil: 7 lb/10^3 gal (0.88 kg/10^3 liter)

[d] Based on References 1 through 5. S is the percentage, by weight, of sulfur in the oil.

[e] Based on References 3 through 5 and 8 through 10. Carbon monoxide emissions may increase by a factor of 10 to 100 if a unit is improperly operated or not well maintained.

[f] Based on References 1, 3 through 5, and 10. Hydrocarbon emissions are generally negligible unless unit is improperly operated or not well maintained, in which case emissions may increase by several orders of magnitude.

[g] Based on References 1 through 5 and 8 through 11.

[h] Use 50 lb/10^3 gal (6.25 kg/10^3 liter) for tangentially fired boilers and 105 lb/10^3 gal (12.6 kg/10^3 liter) for all others, at full load, and normal (>15 percent) excess air. At reduced loads, NO_x emissions are reduced by 0.5 to 1 percent, on the average, for every percentage reduction in boiler load.

[i] Several combustion modifications can be employed for NO_x reduction: (1) limited excess air firing can reduce NO_x emissions by 5 to 30 percent, (2) staged combustion can reduce NO_x emissions by 20 to 45 percent, and (3) flue gas recirculation can reduce NO_x emissions by 10 to 45 percent. Combinations of the modifications have been employed to reduce NO_x emissions by as much as 60 percent in certain boilers. See section 1.4 for a discussion of these NO_x-reducing techniques.

[j] Nitrogen oxides emissions from residual oil combustion in industrial and commercial boilers are strongly dependent on the fuel nitrogen content and can be estimated more accurately by the following empirical relationship:

$$\text{lb } NO_2/10^3 \text{ gal} = 22 + 400 (N)^2$$
$$[\text{kg } NO_2/10^3 \text{ liters} = 2.75 + 50 (N)^2]$$

Where: N is the percentage, by weight, of nitrogen in the oil. Note: For residual oils having high (>0.5%, by weight) nitrogen contents, one should use 120 lb $NO_2/10^3$ gal (15 kg $NO_2/10^3$ liter) as an emission factor.

3.1<

1.3.2.3 Nitrogen Oxides (NO_x)[1-6, 8-11, 14] – Two mechanisms form nitrogen oxides: oxidation of fuel-bound nitrogen and thermal fixation of the nitrogen present in combustion air. Fuel NO_x are primarily a function of the nitrogen content of the fuel and the available oxygen (on the average, about 45 percent of the fuel nitrogen is converted to NO_x, but this may vary from 20 to 70 percent). Thermal NO_x, on the other hand, are largely a function of peak flame temperature and available oxygen – factors which are dependent on boiler size, firing configuration, and operating practices.

Fuel nitrogen conversion is the more important NO_x-forming mechanism in boilers firing residual oil. Except in certain large units having unusually high peak flame temperatures, or in units firing a low-nitrogen residual oil, fuel NO_x will generally account for over 50 percent of the total NO_x generated. Thermal fixation, on the other hand, is the predominant NO_x-forming mechanism in units firing distillate oils, primarily because of the negligible nitrogen content in these lighter oils. Because distillate-oil-fired boilers usually have low heat release rates, however, the quantity of thermal NO_x formed in them is less than in larger units.

A number of variables influence how much NO_x is formed by these two mechanisms. One important variable is firing configuration. Nitrogen oxides emissions from tangentially (corner) fired boilers are, on the average, only half those of horizontally opposed units. Also important are the firing practices employed during boiler operation. The use of limited excess air firing, flue gas recirculation, staged combustion, or some combination thereof, may result in NO_x reductions ranging from 5 to 60 percent. (See section 1.4 for a discussion of these techniques.) Load reduction can likewise decrease NO_x production. Nitrogen oxides emissions may be reduced from 0.5 to 1 percent for each percentage reduction in load from full load operation. It should be noted that most of these variables, with the exception of excess air, are applicable only in large oil-fired boilers. Limited excess air firing is possible in many small boilers, but the resulting NO_x reductions are not nearly as significant.

1.3.2.4 Other Pollutants[1, 3-5, 8-10, 14] – As a rule, only minor amounts of hydrocarbons and carbon monoxide will be produced during fuel oil combustion. If a unit is operated improperly or not maintained, however, the resulting concentrations of these pollutants may increase by several orders of magnitude. This is most likely to be the case with small, often unattended units.

1.3.3 Controls

Various control devices and/or techniques may be employed on oil-fired boilers depending on the type of boiler and the pollutant being controlled. All such controls may be classified into three categories: boiler modification, fuel substitution, and flue gas cleaning.

1.3.3.1 Boiler Modification[1-4, 8, 9, 13, 14] – Boiler modification includes any physical change in the boiler apparatus itself or in the operation thereof. Maintenance of the burner system, for example, is important to assure proper atomization and subsequent minimization of any unburned combustibles. Periodic tuning is important in small units to maximize operating efficiency and minimize pollutant emissions, particularly smoke and CO. Combustion modifications such as limited excess air firing, flue gas recirculation, staged combustion, and reduced load operation all result in lowered NO_x emissions in large facilities. (See Table 1.3-1 for specific reductions possible through these combustion modifications.)

1.3.3.2 Fuel Substitution[3-5, 12] – Fuel substitution, that is, the firing of "cleaner" fuel oils, can substantially reduce emissions of a number of pollutants. Lower sulfur oils, for instance, will reduce SO_x emissions in all boilers regardless of size or type of unit or grade of oil fired. Particulates will generally be reduced when a better grade of oil is fired. Nitrogen oxide emissions will be reduced by switching to either a distillate oil or a residual oil containing less nitrogen. The practice of fuel substitution, however, may be limited by the ability of a given operation to fire a better grade of oil as well as the cost and availability thereof.

1.3.3.3 Flue Gas Cleaning[6, 15-21] – Flue gas cleaning equipment is generally only employed on large oil-fired boilers. Mechanical collectors, a prevalent type of control device, are primarily useful in controlling particulates generated during soot blowing, during upset conditions, or when a very dirty, heavy oil is fired. During these situations, high efficiency cyclonic collectors can effect up to 85 percent control of particulate. Under normal firing conditions, however, or when a clean oil is combusted, cyclonic collectors will not be nearly as effective.

Electrostatic precipitators are commonly found in power plants that at one time fired coal. Precipitators that were designed for coal flyash provide only 40 to 60 percent control of oil-fired particulate. Collection efficiencies of up to 90 percent, however, have been reported for new or rebuilt devices that were specifically designed for oil-firing units.

Scrubbing systems have been installed on oil-fired boilers, especially of late, to control both sulfur oxides and particulate. These systems can achieve SO_2 removal efficiencies of up to 90 to 95 percent and provide particulate control efficiencies on the order of 50 to 60 percent. The reader should consult References 20 and 21 for details on the numerous types of flue gas desulfurization systems currently available or under development.

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1.4 NATURAL GAS COMBUSTION

Revised by Thomas Lahre

1.4.1 General [1,2]

Natural gas has become one of the major fuels used throughout the country. It is used mainly for power generation, for industrial process steam and heat production, and for domestic and commercial space heating. The primary component of natural gas is methane, although varying amounts of ethane and smaller amounts of nitrogen, helium, and carbon dioxide are also present. The average gross heating value of natural gas is approximately 1050 Btu/stdft^3 (9350 kcal/$\underline{N}$m^3), varying generally between 1000 and 1100 Btu/stdft^3 (8900 to 9800 kcal/$\underline{N}$m^3).

Because natural gas in its original state is a gaseous, homogenous fluid, its combustion is simple and can be precisely controlled. Common excess air rates range from 10 to 15 percent; however, some large units operate at excess air rates as low as 5 percent to maximize efficiency and minimize nitrogen oxide (NO_x) emissions.

1.4.2 Emissions and Controls [3-16]

Even though natural gas is considered to be a relatively clean fuel, some emissions can occur from the combustion reaction. For example, improper operating conditions, including poor mixing, insufficient air, etc., may cause large amounts of smoke, carbon monoxide, and hydrocarbons to be produced. Moreover, because a sulfur-containing mercaptan is added to natural gas for detection purposes, small amounts of sulfur oxides will also be produced in the combustion process.

Nitrogen oxides are the major pollutants of concern when burning natural gas. Nitrogen oxide emissions are a function of the temperature in the combustion chamber and the rate of cooling of the combustion products. Emission levels generally vary considerably with the type and size of unit and are also a function of loading.

In some large boilers, several operating modifications have been employed for NO_x control. Staged combustion, for example, including off-stoichiometric firing and/or two-stage combustion, can reduce NO_x emissions by 30 to 70 percent. In off-stoichiometric firing, also called "biased firing," some burners are operated fuel-rich, some fuel-lean, while others may supply air only. In two-staged combustion, the burners are operated fuel-rich (by introducing only 80 to 95 percent stoichiometric air) with combustion being completed by air injected above the flame zone through second-stage "NO-ports." In staged combustion, NO_x emissions are reduced because the bulk of combustion occurs under fuel-rich, reducing conditions.

Other NO_x-reducing modifications include low excess air firing and flue gas recirculation. In low excess air firing, excess air levels are kept as low as possible without producing unacceptable levels of unburned combustibles (carbon monoxide, hydrocarbons, and smoke) and/or other operational problems. This technique can reduce NO_x emissions by 10 to 30 percent primarily because of the lack of availability of oxygen during combustion. Flue gas recirculation into the primary combustion zone, because the flue gas is relatively cool and oxygen deficient, can also lower NO_x emissions by 20 to 60 percent depending on the amount of gas recirculated. At present only a few systems have this capability, however.

Combinations of the above combustion modifications may also be employed to further reduce NO_x emissions. In some boilers, for instance, NO_x reductions as high as 70 to 90 percent have been produced as a result of employing several of these techniques simultaneously. In general, however, because the net effect of any of these combinations varies greatly, it is difficult to predict what the overall reductions will be in any given unit.

Emission factors for natural gas combustion are presented in Table 1.4-1. Flue gas cleaning equipment has not been utilized to control emissions from natural gas combustion equipment.

Table 1.4-1. EMISSION FACTORS FOR NATURAL-GAS COMBUSTION
EMISSION FACTOR RATING: A

	Type of unit					
	Power plant		Industrial process boiler		Domestic and commercial heating	
Pollutant	$lb/10^6\ ft^3$	$kg/10^6\ m^3$	$lb/10^6\ ft^3$	$kg/10^6\ m^3$	$lb/10^6\ ft^3$	$kg/10^6\ m^3$
Particulates[a]	5-15	80-240	5-15	80-240	5-15	80-240
Sulfur oxides (SO_2)[b]	0.6	9.6	0.6	9.6	0.6	9.6
Carbon monoxide[c]	17	272	17	272	20	320
Hydrocarbons (as CH_4)[d]	1	16	3	48	8	128
Nitrogen oxides (NO_2)[e]	700[f-h]	11,200[f-h]	(120-230)[i]	(1920-3680)[i]	(80-120)[j]	(1280-1920)[j]

[a] References 4,7,8,12.

[b] Reference 4 (based on an average sulfur content of natural gas of 2000 $gr/10^6\ stdft^3$ (4600 $g/10^6\ \underline{N}m^3$).

[c] References 5, 8-12.

[d] References 8, 9, 12.

[e] References 3-9, 12-16.

[f] Use 300 $lb/10^6\ stdft^3$ (4800 $kg/10^6\ \underline{N}m^3$) for tangentially fired units.

[g] At reduced loads, multiply this factor by the load reduction coefficient given in Figure 1.4-1.

[h] See text for potential NO_x reductions due to combustion modifications. Note that the NO_x reduction from these modifications will also occur at reduced load conditions.

[i] This represents a typical range for many industrial boilers. For large industrial units (> 100 MMBtu/hr) use the NO_x factors presented for power plants.

[j] Use 80 (1280) for domestic heating units and 120 (1920) for commercial units.

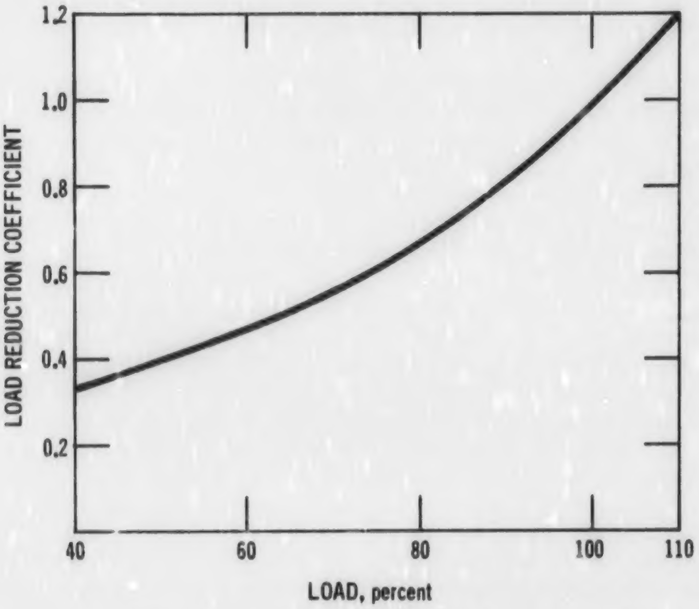

Figure 1.4-1. Load reduction coefficient as function of boiler load. (Used to determine NO_x reductions at reduced loads in large boilers.)

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1.5 LIQUEFIED PETROLEUM GAS COMBUSTION

Revised by Thomas Lahre

1.5.1 General[1]

Liquefied petroleum gas, commonly referred to as LPG, consists mainly of butane, propane, or a mixture of the two, and of trace amounts of propylene and butylene. This gas, obtained from oil or gas wells as a by-product of gasoline refining, is sold as a liquid in metal cylinders under pressure and, therefore, is often called bottled gas. LPG is graded according to maximum vapor pressure with Grade A being predominantly butane, Grade F being predominantly propane, and Grades B through E consisting of varying mixtures of butane and propane. The heating value of LPG ranges from 97,400 Btu/gallon (6,480 kcal/liter) for Grade A to 90,500 Btu/gallon (6,030 kcal/liter) for Grade F. The largest market for LPG is the domestic-commercial market, followed by the chemical industry and the internal combustion engine.

1.5.2 Emissions[1]

LPG is considered a "clean" fuel because it does not produce visible emissions. Gaseous pollutants such as carbon monoxide, hydrocarbons, and nitrogen oxides do occur, however. The most significant factors affecting these emissions are the burner design, adjustment, and venting.[2] Improper design, blocking and clogging of the flue vent, and lack of combustion air result in improper combustion that causes the emission of aldehydes, carbon monoxide, hydrocarbons, and other organics. Nitrogen oxide emissions are a function of a number of variables including temperature, excess air, and residence time in the combustion zone. The amount of sulfur dioxide emitted is directly proportional to the amount of sulfur in the fuel. Emission factors for LPG combustion are presented in Table 1.5-1.

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Table 1.5-1. EMISSION FACTORS FOR LPG COMBUSTION[a]
EMISSION FACTOR RATING: C

Pollutant	Industrial process furnaces				Domestic and commercial furnaces			
	Butane		Propane		Butane		Propane	
	lb/10^3 gal	kg/10^3 liters	lb/10^3 gal	kg/10^3 liters	lb/10^3 gal	kg/10^3 liters	lb/10^3 gal	kg/10^3 liters
Particulates	1.8	0.22	1.7	0.20	1.9	0.23	1.8	0.22
Sulfur oxides[b]	0.09S	0.01S	0.09S	0.01S	0.09S	0.01S	0.09S	0.01S
Carbon monoxide	1.6	0.19	1.5	0.18	2.0	0.24	1.9	0.23
Hydrocarbons	0.3	0.036	0.3	0.036	0.8	0.096	0.7	0.084
Nitrogen oxides[c]	12.1	1.45	11.2	1.35	(8 to 12)[d]	(1.0 to 1.5)[d]	(7 to 11)[d]	(0.8 to 1.3)[d]

[a] LPG emission factors calculated assuming emissions (excluding sulfur oxides) are the same, on a heat input basis, as for natural gas combustion.

[b] S equals sulfur content expressed in grains per 100 ft^3 gas vapor; e.g., if the sulfur content is 0.16 grain per 100 ft^3 (0.366 g/100 m^3) vapor, the SO_2 emission factor would be 0.09 x 0.16 or 0.014 lb SO_2 per 1000 gallons (0.01 x 0.366 or 0.0018 kg $SO_2/10^3$ liters) butane burned.

[c] Expressed as NO_2.

[d] Use lower value for domestic units and higher value for commercial units.

1.6 WOOD/BARK WASTE COMBUSTION IN BOILERS

Revised by Thomas Lahre

1.6.1 General [1-3]

Today, the burning of wood/bark waste in boilers is largely confined to those industries where it is available as a by-product. It is burned both to recover heat energy and to alleviate a potential solid waste disposal problem. Wood/bark waste may include large pieces such as slabs, logs, and bark strips as well as smaller pieces such as ends, shavings, and sawdust. Heating values for this waste range from 8000 to 9000 Btu/lb, on a dry basis; however, because of typical moisture contents of 40 to 75 percent, the as-fired heating values for many wood/bark waste materials range as low as 4000 to 6000 Btu/lb. Generally, bark is the major type of waste burned in pulp mills; whereas, a variable mixture of wood and bark waste, or wood waste alone, is most frequently burned in the lumber, furniture, and plywood industries.

1.6.2 Firing Practices [1-3]

A variety of boiler firing configurations are utilized for burning wood/bark waste. One common type in smaller operations is the Dutch Oven, or extension type of furnace with a flat grate. In this unit the fuel is fed through the furnace roof and burned in a cone-shaped pile on the grate. In many other, generally larger, operations, more conventional boilers have been modified to burn wood/bark waste. These units may include spreader stokers with traveling grates, vibrating grate stokers, etc., as well as tangentially fired or cyclone fired boilers. Generally, an auxiliary fuel is burned in these units to maintain constant steam when the waste fuel supply fluctuates and/or to provide more steam than is possible from the waste supply alone.

1.6.3 Emissions [1,2,4-8]

The major pollutant of concern from wood/bark boilers is particulate matter although other pollutants, particularly carbon monoxide, may be emitted in significant amounts under poor operating conditions. These emissions depend on a number of variables including (1) the composition of the waste fuel burned, (2) the degree of fly-ash reinjection employed, and (3) furnace design and operating conditions.

The composition of wood/bark waste depends largely on the industry from whence it originates. Pulping operations, for instance, produce great quantities of bark that may contain more than 70 percent moisture (by weight) as well as high levels of sand and other noncombustibles. Because of this, bark boilers in pulp mills may emit considerable amounts of particulate matter to the atmosphere unless they are well controlled. On the other hand, some operations such as furniture manufacture, produce a clean, dry (5 to 50 percent moisture) wood waste that results in relatively few particulate emissions when properly burned. Still other operations, such as sawmills, burn a variable mixture of bark and wood waste that results in particulate emissions somewhere in between these two extremes.

Fly-ash reinjection, which is commonly employed in many larger boilers to improve fuel-use efficiency, has a considerable effect on particulate emissions. Because a fraction of the collected fly-ash is reinjected into the boiler, the dust loading from the furnace, and consequently from the collection device, increases significantly per ton of wood waste burned. It is reported that full reinjection can cause a 10-fold increase in the dust loadings of some systems although increases of 1.2 to 2 times are more typical for boilers employing 50 to 100 percent reinjection. A major factor affecting this dust loading increase is the extent to which the sand and other non-combustibles can be successfully separated from the fly-ash before reinjection to the furnace.

Furnace design and operating conditions are particularly important when burning wood and bark waste. For example, because of the high moisture content in this waste, a larger area of refractory surface should be provided to dry the fuel prior to combustion. In addition, sufficient secondary air must be supplied over the fuel bed to burn the volatiles that account for most of the combustible material in the waste. When proper drying conditions do not exist, or when sufficient secondary air is not available, the combustion temperature is lowered, incomplete combustion occurs, and increased particulate, carbon monoxide, and hydrocarbon emissions will result.

Emission factors for wood waste boilers are presented in Table 1.6-1. For boilers where fly-ash reinjection is employed, two factors are shown: the first represents the dust loading reaching the control equipment; the value in parenthesis represents the dust loading after controls assuming about 80 percent control efficiency. All other factors represent uncontrolled emissions.

Table 1.6-1. EMISSION FACTORS FOR WOOD AND BARK WASTE COMBUSTION IN BOILERS
EMISSION FACTOR RATING: B

Pollutant	Emissions	
	lb/ton	kg/MT
Particulates[a]		
Bark[b,c]		
With fly-ash reinjection[d]	75 (15)	37.5 (7.5)
Without fly-ash reinjection	50	25
Wood/bark mixture[b,e]		
With fly-ash reinjection[d]	45 (9)	22.5 (4.5)
Without fly-ash reinjection	30	15
Wood[f,g]	5-15	2.5-7.5
Sulfur oxides (SO_2)[h,i]	1.5	0.75
Carbon monoxide[j]	2-60	1-30
Hydrocarbons[k]	2-70	1-35
Nitrogen oxides (NO_2)[1]	10	5

[a] These emission factors were determined for boilers burning gas or oil as an auxiliary fuel, and it was assumed all particulates resulted from the waste fuel alone. When coal is burned as an auxiliary fuel, the appropriate emission factor from Table 1.1-2 should be used in addition to the above factor.

[b] These factors based on an as-fired moisture content of 50 percent.

[c] References 2, 4, 9.

[d] This factor represents a typical dust loading reaching the control equipment for boilers employing fly-ash reinjection. The value in parenthesis represents emissions after the control equipment assuming an average efficiency of 80 percent.

[e] References 7, 10.

[f] This waste includes clean, dry (5 to 50 percent moisture) sawdust, shavings, ends, etc., and no bark. For well designed and operated boilers use lower value and higher values for others. This factor is expressed on an as-fired moisture content basis assuming no fly-ash reinjection.

[g] References 11-13.

[h] This factor is calculated by material balance assuming a maximum sulfur content of 0.1 percent in the waste. When auxiliary fuels are burned, the appropriate factors from Tables 1.1-2, 1.3-1, or 1.4-1 should be used in addition to determine sulfur oxide emissions.

[i] References 1, 5, 7.

[j] This factor is based on engineering judgment and limited data from references 11 through 13. Use lower values for well designed and operated boilers.

[k] This factor is based on limited data from references 13 through 15. Use lower values for well designed and operated boilers.

[1] Reference 16.

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44<

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1.7 LIGNITE COMBUSTION

by Thomas Lahre

1.7.1 General[1-4]

Lignite is a geologically young coal whose properties are intermediate to those of bituminous coal and peat. It has a high moisture content (35 to 40 percent, by weight) and a low heating value (6000 to 7500 Btu/lb, wet basis) and is generally only burned close to where it is mined, that is, in the midwestern States centered about North Dakota and in Texas. Although a small amount is used in industrial and domestic situations, lignite is mainly used for steam-electric production in power plants. In the past, lignite was mainly burned in small stokers; today the trend is toward use in much larger pulverized-coal-fired or cyclone-fired boilers.

The major advantage to firing lignite is that, in certain geographical areas, it is plentiful, relatively low in cost, and low in sulfur content (0.4 to 1 percent by weight, wet basis). Disadvantages are that more fuel and larger facilities are necessary to generate each megawatt of power than is the case with bituminous coal. There are several reasons for this. First, the higher moisture content of lignite means that more energy is lost in the gaseous products of combustion, which reduces boiler efficiency. Second, more energy is required to grind lignite to the specified size needed for combustion, especially in pulverized coal-fired units. Third, greater tube spacing and additional soot blowing are required because of the higher ash-fouling tendencies of lignite. Fourth, because of its lower heating value, more fuel must be handled to produce a given amount of power because lignite is not generally cleaned or dried prior to combustion (except for some drying that may occur in the crusher or pulverizer and during subsequent transfer to the burner). Generally, no major problems exist with the handling or combustion of lignite when its unique characteristics are taken into account.

1.7.2 Emissions and Controls[2-8]

The major pollutants of concern when firing lignite, as with any coal, are particulates, sulfur oxides, and nitrogen oxides. Hydrocarbon and carbon monoxide emissions are usually quite low under normal operating conditions.

Particulate emissions appear most dependent on the firing configuration in the boiler. Pulverized-coal-fired units and spreader stokers, which fire all or much of the lignite in suspension, emit the greatest quantity of flyash per unit of fuel burned. Both cyclones, which collect much of the ash as molten slag in the furnace itself, and stokers (other than spreader stokers), which retain a large fraction of the ash in the fuel bed, emit less particulate matter. In general, the higher sodium content of lignite, relative to other coals, lowers particulate emissions by causing much of the resulting flyash to deposit on the boiler tubes. This is especially the case in pulverized-coal-fired units wherein a high fraction of the ash is suspended in the combustion gases and can readily come into contact with the boiler surfaces.

Nitrogen oxides emissions are mainly a function of the boiler firing configuration and excess air. Cyclones produce the highest NO_x levels, primarily because of the high heat-release rates and temperatures reached in the small furnace sections of the boiler. Pulverized-coal-fired boilers produce less NO_x than cyclones because combustion occurs over a larger volume, which results in lower peak flame temperatures. Tangentially fired boilers produce the lowest NO_x levels in this category. Stokers produce the lowest NO_x levels mainly because most existing units are much smaller than the other firing types. In most boilers, regardless of firing configuration, lower excess air during combustion results in lower NO_x emissions.

Sulfur oxide emissions are a function of the alkali (especially sodium) content of the lignite ash. Unlike most fossil fuel combustion, in which over 90 percent of the fuel sulfur is emitted as SO_2, a significant fraction of the sulfur in lignite reacts with the ash components during combustion and is retained in the boiler ash deposits and flyash. Tests have shown that less than 50 percent of the available sulfur may be emitted as SO_2 when a high-sodium lignite is burned, whereas, more than 90 percent may be emitted with low-sodium lignite. As a rough average, about 75 percent of the fuel sulfur will be emitted as SO_2, with the remainder being converted to various sulfate salts.

46<

Air pollution controls on lignite-fired boilers in the United States have mainly been limited to cyclone collectors, which typically achieve 60 to 75 percent collection efficiency on lignite flyash. Electrostatic precipitators, which are widely utilized in Europe on lignitic coals and can effect 99+ percent particulate control, have seen only limited application in the United States to date although their use will probably become widespread on newer units in the future.

Nitrogen oxides reduction (up to 40 percent) has been demonstrated using low excess air firing and staged combustion (see section 1.4 for a discussion of these techniques); it is not yet known, however, whether these techniques can be continuously employed on lignite combustion units without incurring operational problems. Sulfur oxides reduction (up to 50 percent) and some particulate control can be achieved through the use of high sodium lignite. This is not generally considered a desirable practice, however, because of the increased ash fouling that may result.

Emission factors for lignite combustion are presented in Table 1.7-1.

Table 1.7-1. EMISSIONS FROM LIGNITE COMBUSTION WITHOUT CONTROL EQUIPMENT[a]
EMISSION FACTOR RATING: B

	Type of boiler							
	Pulverized-coal		Cyclone		Spreaker stoker		Other stokers	
Pollutant	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Particulate[b]	7.0A[c]	3.5A[c]	6A	3A	7.0A[d]	3.5A[d]	3.0A	1.5A
Sulfur oxides[e]	30S	15S	30S	15S	30S	15S	30S	15S
Nitrogen oxides[f]	14(8)[g,h]	7(4)[g,h]	17	8.5	6	3	6	3
Hydrocarbons[i]	<1.0	<0.5	<1.0	<0.5	1.0	0.5	1.0	0.5
Carbon monoxide[i]	1.0	0.5	1.0	0.5	2	1	2	1

[a] All emission factors are expressed in terms of pounds of pollutant per ton (kilograms of pollutant per metric ton) of lignite burned, wet basis (35 to 40 percent moisture, by weight).

[b] A is the ash content of the lignite by weight, wet basis. Factors based on References 5 and 6.

[c] This factor is based on data for dry-bottom, pulverized-coal-fired units only. It is expected that this factor would be lower for wet-bottom units.

[d] Limited data preclude any determination of the effect of flyash reinjection. It is expected that particulate emissions would be greater when reinjection is employed.

[e] S is the sulfur content of the lignite by weight, wet basis. For a high sodium-ash lignite ($Na_2O > 8$ percent) use 17S lb/ton (8.5S kg/MT); for a low sodium-ash lignite ($Na_2O < 2$ percent), use 35S lb/ton (17.5S kg/MT). For intermediate sodium-ash lignite, or when the sodium-ash content is unknown, use 30S lb/ton (15S kg/MT)). Factors based on References 2, 5, and 6.

[f] Expressed as NO_2. Factors based on References 2, 3, 5, 7, and 9.

[g] Use 14 lb/ton (7 kg/MT) for front-wall-fired and horizontally opposed wall-fired units and 8 lb/ton (4 kg/MT) for tangentially fired units.

[h] Nitrogen oxide emissions may be reduced by 20 to 40 percent with low excess air firing and/or staged combustion in front-fired and opposed-wall-fired units and cyclones.

[i] These factors are based on the similarity of lignite combustion to bituminous coal combustion and on limited data in Reference 7.

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1.8 BAGASSE COMBUSTION IN SUGAR MILLS

by Tom Lahre

1.8.1 General[1]

Bagasse is the fibrous residue from sugar cane that has been processed in a sugar mill. (See Section 6.12 for a brief general description of sugar cane processing.) It is fired in boilers to eliminate a large solid waste disposal problem and to produce steam and electricity to meet the mill's power requirements. Bagasse represents about 30 percent of the weight of the raw sugar cane. Because of the high moisture content (usually at least 50 percent, by weight) a typical heating value of wet bagasse will range from 3000 to 4000 Btu/lb (1660 to 2220 kcal/kg). Fuel oil may be fired with bagasse when the mill's power requirements cannot be met by burning only bagasse or when bagasse is too wet to support combustion.

The United States sugar industry is located in Florida, Louisiana, Hawaii, Texas, and Puerto Rico. Except in Hawaii, where raw sugar production takes place year round, sugar mills operate seasonally, from 2 to 5 months per year.

Bagasse is commonly fired in boilers employing either a solid hearth or traveling grate. In the former, bagasse is gravity fed through chutes and forms a pile of burning fibers. The burning occurs on the surface of the pile with combustion air supplied through primary and secondary ports located in the furnace walls. This kind of boiler is common in older mills in the sugar cane industry. Newer boilers, on the other hand, may employ traveling-grate stokers. Underfire air is used to suspend the bagasse, and overfired air is supplied to complete combustion. This kind of boiler requires bagasse with a higher percentage of fines, a moisture content not over 50 percent, and more experienced operating personnel.

1.8.2 Emissions and Controls[1]

Particulate is the major pollutant of concern from bagasse boilers. Unless an auxiliary fuel is fired, few sulfur oxides will be emitted because of the low sulfur content (<0.1 percent, by weight) of bagasse. Some nitrogen oxides are emitted, although the quantities appear to be somewhat lower (on an equivalent heat input basis) than are emitted from conventional fossil fuel boilers.

Particulate emissions are reduced by the use of multi-cyclones and wet scrubbers. Multi-cyclones are reportedly 20 to 60 percent efficient on particulate from bagasse boilers, whereas scrubbers (either venturi or the spray impingement type) are usually 90 percent or more efficient. Other types of control equipment have been investigated but have not been found to be practical.

Emission factors for bagasse fired boilers are shown in Table 1.8-1.

Table 1.8-1. EMISSION FACTORS FOR UNCONTROLLED BAGASSE BOILERS
EMISSION FACTOR RATING: C

	Emission factors			
	lb/10^3 lb steam[a]	g/kg steam[a]	lb/ton bagasse[b]	kg/MT bagasse[b]
Particulate[c]	4	4	16	8
Sulfur oxides	d	d	d	d
Nitrogen oxides[e]	0.3	0.3	1.2	0.6

[a] Emission factors are expressed in terms of the amount of steam produced, as most mills do not monitor the amount of bagasse fired. These factors should be applied only to that fraction of steam resulting from bagasse combustion. If a significant amount (>25% of total Btu input) of fuel oil is fired with the bagasse, the appropriate emission factors from Table 1.3-1 should be used to estimate the emission contributions from the fuel oil.

[b] Emissions are expressed in terms of wet bagasse, containing approximately 50 percent moisture, by weight. As a rule of thumb, about 2 pounds (2 kg) of steam are produced from 1 pound (1kg) of wet bagasse.

[c] Multi-cyclones are reportedly 20 to 60 percent efficient on particulate from bagasse boilers. Wet scrubbers are capable of effecting 90 or more percent particulate control. Based on Reference 1.

[d] Sulfur oxide emissions from the firing of bagasse alone would be expected to be negligible as bagasse typically contains less than 0.1 percent sulfur, by weight. If fuel oil is fired with bagasse, the appropriate factors from Table 1.3-1 should be used to estimate sulfur oxide emissions.

[e] Based on Reference 1.

Reference for Section 1.8

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1.9 RESIDENTIAL FIREPLACES

by Tom Lahre

1.9.1 General[1,2]

Fireplaces are utilized mainly in homes, lodges, etc., for supplemental heating and for their aesthetic effect. Wood is most commonly burned in fireplaces; however, coal, compacted wood waste "logs," paper, and rubbish may all be burned at times. Fuel is generally added to the fire by hand on an intermittent basis.

Combustion generally takes place on a raised grate or on the floor of the fireplace. Combustion air is supplied by natural draft, and may be controlled, to some extent, by a damper located in the chimney directly above the firebox. It is common practice for dampers to be left completely open during the fire, affording little control of the amount of air drawn up the chimney.

Most fireplaces heat a room by radiation, with a significant fraction of the heat released during combustion (estimated at greater than 70 percent) lost in the exhaust gases or through the fireplace walls. In addition, as with any fuel-burning, space-heating device, some of the resulting heat energy must go toward warming the air that infiltrates into the residence to make up for the air drawn up the chimney. The net effect is that fireplaces are extremely inefficient heating devices. Indeed, in cases where combustion is poor, where the outside air is cold, or where the fire is allowed to smolder (thus drawing air into a residence without producing apreciable radiant heat energy) a net heat loss may occur in a residence due to the use of a fireplace. Fireplace efficiency may be improved by a number of devices that either reduce the excess air rate or transfer some of the heat back into the residence that is normally lost in the exhaust gases or through the fireplace walls.

1.9.2 Emissions[1,2]

The major pollutants of concern from fireplaces are unburnt combustibles–carbon monoxide and smoke. Significant quantities of these pollutants are produced because fireplaces are grossly inefficient combustion devices due to high, uncontrolled excess air rates, low combustion temperatures, and the absence of any sort of secondary combustion. The last of these is especially important when burning wood because of its typically high (80 percent, on a dry weight basis)[3] volatile matter content.

Because most wood contains negligible sulfur, very few sulfur oxides are emitted. Sulfur oxides will be produced, of course, when coal or other sulfur-bearing fuels are burned. Nitrogen oxide emissions from fireplaces are expected to be negligible because of the low combustion temperatures involved.

Emission factors for wood and coal combustion in residential fireplaces are given in Table 1.9-1.

Table 1.9-1. EMISSION FACTORS FOR RESIDENTIAL FIREPLACES
EMISSION FACTOR RATING: C

Pollutant	Wood		Coal[a]	
	lb/ton	kg/MT	lb/ton	kg/MT
Particulate	20[b]	10[b]	30[c]	15[c]
Sulfur oxides	0[d]	0[d]	36S[e]	36S[e]
Nitrogen oxides	1[f]	0.5[f]	3	1.5
Hydrocarbons	5[g]	2.5[g]	20	10
Carbon monoxide	120[h]	60[h]	90	45

[a] All coal emission factors, except particulate, are based on data in Table 1.1-2 of Section 1.1 for hand-fired units.

[b] This includes condensable particulate. Only about 30 percent of this is filterable particulate as determined by EPA Method 5 (front-half catch).[4] Based on limited data from Reference 1.

[c] This includes condensable particulate. About 50 percent of this is filterable particulate as determined by EPA Method 5 (front-half catch).[4] Based on limited data from Reference 1.

[d] Based on negligible sulfur content in most wood.[3]

[e] S is the sulfur content, on a weight percent basis, of the coal.

[f] Based on data in Table 2.3-1 in Section 2.3 for wood waste combustion in conical burners.

[g] Nonmethane volatile hydrocarbons. Based on limited data from Reference 1.

[h] Based on limited data from Reference 1.

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2. SOLID WASTE DISPOSAL

Revised by Robert Rosensteel

As defined in the Solid Waste Disposal Act of 1965, the term "solid waste" means garbage, refuse, and other discarded solid materials, including solid-waste materials resulting from industrial, commercial, and agricultural operations, and from community activities. It includes both combustibles and noncombustibles.

Solid wastes may be classified into four general categories: urban, industrial, mineral, and agricultural. Although urban wastes represent only a relatively small part of the total solid wastes produced, this category has a large potential for air pollution since in heavily populated areas solid waste is often burned to reduce the bulk of material requiring final disposal.[1] The following discussion will be limited to the urban and industrial waste categories.

An average of 5.5 pounds (2.5 kilograms) of urban refuse and garbage is collected per capita per day in the United States.[2] This figure does not include uncollected urban and industrial wastes that are disposed of by other means. Together, uncollected urban and industrial wastes contribute at least 4.5 pounds (2.0 kilograms) per capita per day. The total gives a conservative per capita generation rate of 10 pounds (4.5 kilograms) per day of urban and industrial wastes. Approximately 50 percent of all the urban and industrial waste generated in the United States is burned, using a wide variety of combustion methods with both enclosed and open burning[3]. Atmospheric emissions, both gaseous and particulate, result from refuse disposal operations that use combustion to reduce the quantity of refuse. Emissions from these combustion processes cover a wide range because of their dependence upon the refuse burned, the method of combustion or incineration, and other factors. Because of the large number of variables involved, it is not possible, in general, to delineate when a higher or lower emission factor, or an intermediate value should be used. For this reason, an average emission factor has been presented.

References

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2.1 REFUSE INCINERATION

Revised by Robert Rosensteel

2.1.1 Process Description[1-4]

The most common types of incinerators consist of a refractory-lined chamber with a grate upon which refuse is burned. In some newer incinerators water-walled furnaces are used. Combustion products are formed by heating and burning of refuse on the grate. In most cases, since insufficient underfire (undergrate) air is provided to enable complete combustion, additional over-fire air is admitted above the burning waste to promote complete gas-phase combustion. In multiple-chamber incinerators, gases from the primary chamber flow to a small secondary mixing chamber where more air is admitted, and more complete oxidation occurs. As much as 300 percent excess air may be supplied in order to promote oxidation of combustibles. Auxiliary burners are sometimes installed in the mixing chamber to increase the combustion temperature. Many small-size incinerators are single-chamber units in which gases are vented from the primary combustion chamber directly into the exhaust stack. Single-chamber incinerators of this type do not meet modern air pollution codes.

2.1.2 Definitions of Incinerator Categories[1]

No exact definitions of incinerator size categories exist, but for this report the following general categories and descriptions have been selected:

1. *Municipal incinerators* – Multiple-chamber units often have capacities greater than 50 tons (45.3 MT) per day and are usually equipped with automatic charging mechanisms, temperature controls, and movable grate systems. Municipal incinerators are also usually equipped with some type of particulate control device, such as a spray chamber or electrostatic precipitator.

2. *Industrial/commercial incinerators* – The capacities of these units cover a wide range, generally between 50 and 4,000 pounds (22.7 and 1,800 kilograms) per hour. Of either single- or multiple-chamber design, these units are often manually charged and intermittently operated. Some industrial incinerators are similar to municipal incinerators in size and design. Better designed emission control systems include gas-fired afterburners or scrubbing, or both.

3. *Trench Incinerators* – A trench incinerator is designed for the combustion of wastes having relatively high heat content and low ash content. The design of the unit is simple: a U-shaped combustion chamber is formed by the sides and bottom of the pit and air is supplied from nozzles along the top of the pit. The nozzles are directed at an angle below the horizontal to provide a curtain of air across the top of the pit and to provide air for combustion in the pit. The trench incinerator is not as efficient for burning wastes as the municipal multiple-chamber unit, except where careful precautions are taken to use it for disposal of low-ash, high-heat-content refuse, and where special attention is paid to proper operation. Low construction and operating costs have resulted in the use of this incinerator to dispose of materials other than those for which it was originally designed. Emission factors for trench incinerators used to burn three such materials[7] are included in Table 2.1-1.

4. *Domestic incinerators* – This category includes incinerators marketed for residential use. Fairly simple in design, they may have single or multiple chambers and usually are equipped with an auxiliary burner to aid combustion.

Table 2.1-1. EMISSION FACTORS FOR REFUSE INCINERATORS WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: A

Incinerator type	Particulates		Sulfur oxides[b]		Carbon monoxide		Hydrocarbons[c]		Nitrogen oxides[d]	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Municipal[e]										
Multiple chamber, uncontrolled	30	15	2.5	1.25	35	17.5	1.5	0.75	3	1.5
With settling chamber and water spray system[f]	14	7	2.5	1.25	35	17.5	1.5	0.75	3	1.5
Industrial/commercial										
Multiple chamber[g]	7	3.5	2.5[h]	1.25	10	5	3	1.5	3	1.5
Single chamber[i]	15	7.5	2.5[h]	1.25	20	10	15	7.5	2	1
Trench[j]										
Wood	13	6.5	0.1[k]	0.05	NA[l]	NA	NA	NA	4	2
Rubber tires	138	69	NA	NA	NA	NA	NA	NA	NA	NA
Municipal refuse	37	18.5	2.5[h]	1.25	NA	NA	NA	NA	NA	NA
Controlled air[m]	1.4	0.7	1.5	0.75	Neg	Neg	Neg	Neg	10	5
Flue-fed single chamber[n]	30	15	0.5	0.25	20	10	15	7.5	3	1.5
Flue-fed (modified)[o,p]	6	3	0.5	0.25	10	5	3	1.5	10	5
Domestic single chamber										
Without primary burner[q]	35	17.5	0.5	0.25	300	150	100	50	1	0.5
With primary burner[r]	7	3.5	0.5	0.25	Neg	Neg	2	1	2	1
Pathological[s]	8	4	Neg	Neg	Neg	Neg	Neg	Neg	3	1.5

[a] Average factors given based on EPA procedures for incinerator stack testing.

[b] Expressed as sulfur dioxide.

[c] Expressed as methane.

[d] Expressed as nitrogen dioxide.

[e] References 5 and 8 through 14.

[f] Most municipal incinerators are equipped with at least this much control: see Table 2.1-2 for appropriate efficiencies for other controls.

[g] References 3, 5, 10, 13, and 15.

[h] Based on municipal incinerator data.

[i] References 3, 5, 10, and 15.

[j] Reference 7.

[k] Based on data for wood combustion in conical burners.

[l] Not available.

[m] Reference 9.

[n] References 3, 10, 11, 13, 15, and 16.

[o] With afterburners and draft controls.

[p] References 3, 11, and 15.

[q] References 5 and 10.

[r] Reference 5.

[s] References 3 and 9.

5. *Flue-fed incinerators* – These units, commonly found in large apartment houses, are characterized by the charging method of dropping refuse down the incinerator flue and into the combustion chamber. Modified flue-fed incinerators utilize afterburners and draft controls to improve combustion efficiency and reduce emissions.

6. *Pathological incinerators* – These are incinerators used to dispose of animal remains and other organic material of high moisture content. Generally, these units are in a size range of 50 to 100 pounds (22.7 to 45.4 kilograms) per hour. Wastes are burned on a hearth in the combustion chamber. The units are equipped with combustion controls and afterburners to ensure good combustion and minimal emissions.

7. *Controlled air incinerators* – These units operate on a controlled combustion principle in which the waste is burned in the absence of sufficient oxygen for complete combustion in the main chamber. This process generates a highly combustible gas mixture that is then burned with excess air in a secondary chamber, resulting in efficient combustion. These units are usually equipped with automatic charging mechanisms and are characterized by the high effluent temperatures reached at the exit of the incinerators.

2.1.3 Emissions and Controls[1]

Operating conditions, refuse composition, and basic incinerator design have a pronounced effect on emissions. The manner in which air is supplied to the combustion chamber or chambers has, among all the parameters, the greatest effect on the quantity of particulate emissions. Air may be introduced from beneath the chamber, from the side, or from the top of the combustion area. As underfire air is increased, an increase in fly-ash emissions occurs. Erratic refuse charging causes a disruption of the combustion bed and a subsequent release of large quantities of particulates. Large quantities of uncombusted particulate matter and carbon monoxide are also emitted for an extended period after charging of batch-fed units because of interruptions in the combustion process. In continuously fed units, furnace particulate emissions are strongly dependent upon grate type. The use of rotary kiln and reciprocating grates results in higher particulate emissions than the use of rocking or traveling grates.[14] Emissions of oxides of sulfur are dependent on the sulfur content of the refuse. Carbon monoxide and unburned hydrocarbon emissions may be significant and are caused by poor combustion resulting from improper incinerator design or operating conditions. Nitrogen oxide emissions increase with an increase in the temperature of the combustion zone, an increase in the residence time in the combustion zone before quenching, and an increase in the excess air rates to the point where dilution cooling overcomes the effect of increased oxygen concentration.[14]

Table 2.1-2 lists the relative collection efficiencies of particulate control equipment used for municipal incinerators. This control equipment has little effect on gaseous emissions. Table 2.1-1 summarizes the uncontrolled emission factors for the various types of incinerators previously discussed.

Table 2.1-2. COLLECTION EFFICIENCIES FOR VARIOUS TYPES OF MUNICIPAL INCINERATION PARTICULATE CONTROL SYSTEMS[a]

Type of system	Efficiency, %
Settling chamber	0 to 30
Settling chamber and water spray	30 to 60
Wetted baffles	60
Mechanical collector	30 to 80
Scrubber	80 to 95
Electrostatic precipitator	90 to 96
Fabric filter	97 to 99

[a] References 3, 5, 6, and 17 through 21.

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2.2 AUTOMOBILE BODY INCINERATION

Revised by Robert Rosensteel

2.2.1 Process Description

Auto incinerators consist of a single primary combustion chamber in which one or several partially stripped cars are burned. (Tires are removed.) Approximately 30 to 40 minutes is required to burn two bodies simultaneously.[2] As many as 50 cars per day can be burned in this batch-type operation, depending on the capacity of the incinerator. Continuous operations in which cars are placed on a conveyor belt and passed through a tunnel-type incinerator have capacities of more than 50 cars per 8-hour day.

2.2.2 Emissions and Controls[1]

Both the degree of combustion as determined by the incinerator design and the amount of combustible material left on the car greatly affect emissions. Temperatures on the order of 1200°F (650°C) are reached during auto body incineration.[2] This relatively low combustion temperature is a result of the large incinerator volume needed to contain the bodies as compared with the small quantity of combustible material. The use of overfire air jets in the primary combustion chamber increases combustion efficiency by providing air and increased turbulence.

In an attempt to reduce the various air pollutants produced by this method of burning, some auto incinerators are equipped with emission control devices. Afterburners and low-voltage electrostatic precipitators have been used to reduce particulate emissions; the former also reduces some of the gaseous emissions.[3,4] When afterburners are used to control emissions, the temperature in the secondary combustion chamber should be at least 1500°F (815°C). Lower temperatures result in higher emissions. Emission factors for auto body incinerators are presented in Table 2.2-1.

Table 2.2-1. EMISSION FACTORS FOR AUTO BODY INCINERATION[a]
EMISSION FACTOR RATING: B

Pollutants	Uncontrolled		With afterburner	
	lb/car	kg/car	lb/car	kg/car
Particulates[b]	2	0.9	1.5	0.68
Carbon monoxide[c]	2.5	1.1	Neg	Neg
Hydrocarbons (CH_4)[c]	0.5	0.23	Neg	Neg
Nitrogen oxides (NO_2)[d]	0.1	0.05	0.02	0.01
Aldehydes (HCOH)[d]	0.2	0.09	0.06	0.03
Organic acids (acetic)[d]	0.21	0.10	0.07	0.03

[a] Based on 250 lb (113 kg) of combustible material on stripped car body.
[b] References 2 and 4.
[c] Based on data for open burning and References 2 and 5.
[d] Reference 3.

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2.3 CONICAL BURNERS

2.3.1 Process Description[1]

Conical burners are generally a truncated metal cone with a screened top vent. The charge is placed on a raised grate by either conveyor or bulldozer; however, the use of a conveyor results in more efficient burning. No supplemental fuel is used, but combustion air is often supplemented by underfire air blown into the chamber below the grate and by overfire air introduced through peripheral openings in the shell.

2.3.2 Emissions and Controls

The quantities and types of pollutants released from conical burners are dependent on the composition and moisture content of the charged material, control of combustion air, type of charging system used, and the condition in which the incinerator is maintained. The most critical of these factors seems to be the level of maintenance on the incinerators. It is not uncommon for conical burners to have missing doors and numerous holes in the shell, resulting in excessive combustion air, low temperatures, and, therefore, high emission rates of combustible pollutants.[2]

Particulate control systems have been adapted to conical burners with some success. These control systems include water curtains (wet caps) and water scrubbers. Emission factors for conical burners are shown in Table 2.3-1.

Table 2.3-1. EMISSION FACTORS FOR WASTE INCINERATION IN CONICAL BURNERS WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: B

Type of waste	Particulates		Sulfur oxides		Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Municipal refuse[b]	20(10 to 60)[c,d]	10	2	1	60	30	20	10	5	2.5
Wood refuse[e]	1[f] 7[g] 20[h]	0.5 3.5 10	0.1	0.05	130	65	11	5.5	1	0.5

[a] Moisture content as fired is approximately 50 percent for wood waste.

[b] Except for particulates, factors are based on comparison with other waste disposal practices.

[c] Use high side of range for intermittent operations charged with a bulldozer.

[d] Based on Reference 3.

[e] References 4 through 9.

[f] Satisfactory operation: properly maintained burner with adjustable underfire air supply and adjustable, tangential overfire air inlets, approximately 500 percent excess air and 700°F (370°C) exit gas temperature.

[g] Unsatisfactory operation: properly maintained burner with radial overfire air supply near bottom of shell, approximately 1200 percent excess air and 400°F (204°C) exit gas temperature.

[h] Very unsatisfactory operation: improperly maintained burner with radial overfire air supply near bottom of shell and many gaping holes in shell, approximately 1500 percent excess air and 400°F (204°C) exit gas temperature.

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2.4 OPEN BURNING

revised by Tom Lahre
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2.4.1 General[1]

Open burning can be done in open drums or baskets, in fields and yards, and in large open dumps or pits. Materials commonly disposed of in this manner are municipal waste, auto body components, landscape refuse, agricultural field refuse, wood refuse, bulky industrial refuse, and leaves.

2.4.2 Emissions[1-19]

Ground-level open burning is affected by many variables including wind, ambient temperature, composition and moisture content of the debris burned, and compactness of the pile. In general, the relatively low temperatures associated with open burning increase the emission of particulates, carbon monoxide, and hydrocarbons and suppress the emission of nitrogen oxides. Sulfur oxide emissions are a direct function of the sulfur content of the refuse. Emission factors are presented in Table 2.4-1 for the open burning of municipal refuse and automobile components.

Table 2.4-1. EMISSION FACTORS FOR OPEN BURNING OF NONAGRICULTURAL MATERIAL
EMISSION FACTOR RATING: B

	Particulates	Sulfur oxides	Carbon monoxide	Hydrocarbons (CH_4)	Nitrogen oxides
Municipal refuse[a]					
lb/ton	16	1	85	30	6
kg/MT	8	0.5	42	15	3
Automobile components[b,c]					
lb/ton	100	Neg.	125	30	4
kg/MT	50	Neg.	62	15	2

[a] References 2 through 6.
[b] Upholstery, belts, hoses, and tires burned in common.
[c] Reference 2.

Emissions from agricultural refuse burning are dependent mainly on the moisture content of the refuse and, in the case of the field crops, on whether the refuse is burned in a headfire or a backfire. (Headfires are started at the upwind side of a field and allowed to progress in the direction of the wind, whereas backfires are started at the downwind edge and forced to progress in a direction opposing the wind.) Other variables such as fuel loading (how much refuse material is burned per unit of land area) and how the refuse is arranged (that is, in piles, rows, or spread out) are also important in certain instances. Emission factors for open agricultural burning are presented in Table 2.4-2 as a function of refuse type and also, in certin instances, as a function of burning techniques and/or moisture content when these variables are known to significantly affect emissions. Table 2.4-2 also presents typical fuel loading values associated with each type of refuse. These values can be used, along with the corresponding emission factors, to estimate emissions from certain categories of agricultural burning when the specific fuel loadings for a given area are not known.

Emissions from leaf burning are dependent upon the moisture content, density, and ignition location of the leaf piles. Increasing the moisture content of the leaves generally increases the amount of carbon monoxide, hydrocarbon, and particulate emissions. Increasing the density of the piles increases the amount of hydrocarbon and particulate emissions, but has a variable effect on carbon

64<

Table 2.4-2. EMISSION FACTORS AND FUEL LOADING FACTORS FOR OPEN BURNING OF AGRICULTURAL MATERIALS[a]
EMISSION FACTOR RATING: B

Refuse category	Emission factors						Fuel loading factors (waste production)	
	Particulate[b]		Carbon monoxide		Hydrocarbons (as C_6H_{14})			
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	ton/acre	MT/hectare
Field crops[c]								
Unspecified	21	11	117	58	23	12	2.0	4.5
Burning technique not significant[d]								
Asparagus[e]	40	20	150	75	85	42	1.5	3.4
Barley	22	11	157	78	19	10	1.7	3.8
Corn	14	7	108	54	16	8	4.2	9.4
Cotton	8	4	176	88	6	3	1.7	3.8
Grasses	16	8	101	50	19	10		
Pineapple[f]	8	4	112	56	8	4		
Rice[g]	9	4	83	41	10	5	3.0	6.7
Safflower	18	9	144	72	26	13	1.3	2.9
Sorghum	18	9	77	38	9	4	2.9	6.5
Sugar cane[h]	7	4	71	35	10	5	11.0	24.0
Headfire burning[i]								
Alfalfa	45	23	106	53	36	18	0.8	1.8
Bean (red)	43	22	186	93	46	23	2.5	5.6
Hay (wild)	32	16	139	70	22	11	1.0	2.2
Oats	44	22	137	68	33	16	1.6	3.6
Pea	31	16	147	74	38	19	2.5	5.6
Wheat	22	11	128	64	17	9	1.9	4.3
Backfire burning[j]								
Alfalfa	29	14	119	60	37	18	0.8	1.8
Bean (red), pea	14	7	148	72	25	12	2.5	5.6
Hay (wild)	17	8	150	75	17	8	1.0	2.2
Oats	21	11	136	68	18	9	1.6	3.6
Wheat	13	6	108	54	11	6	1.9	4.3
Vine crops	5	3	51	26	7	4	2.5	5.6
Weeds								
Unspecified	15	8	85	42	12	6	3.2	7.2
Russian thistle (tumbleweed)	22	11	309	154	2	1	0.1	0.2
Tules (wild reeds)	5	3	34	17	27	14		
Orchard crops[c,k,l]								
Unspecified	6	3	52	26	10	5	1.6	3.6
Almond	6	3	46	23	8	4	1.6	3.6
Apple	4	2	42	21	4	2	2.3	5.2
Apricot	6	3	49	24	8	4	1.8	4.0
Avocado	21	10	116	58	32	16	1.5	3.4
Cherry	8	4	44	22	10	5	1.0	2.2
Citrus (orange, lemon)	6	3	81	40	12	6	1.0	2.2
Date palm	10	5	56	28	7	4	1.0	2.2
Fig	7	4	57	28	10	5	2.2	4.9

Table 2.4-2 (continued). EMISSION FACTORS AND FUEL LOADING FACTORS FOR OPEN BURNING OF AGRICULTURAL MATERIALS[a]

EMISSION FACTOR RATING: B

Refuse category	Emission factors: Particulate[b] lb/ton	Particulate[b] kg/MT	Carbon monoxide lb/ton	Carbon monoxide kg/MT	Hydrocarbons (as C_6H_{14}) lb/ton	Hydrocarbons (as C_6H_{14}) kg/MT	Fuel loading factors (waste production) ton/acre	Fuel loading factors (waste production) MT/hectare
Orchard crops[c,k,l] (continued)								
Nectarine	4	2	33	16	4	2	2.0	4.5
Olive	12	6	114	57	18	9	1.2	2.7
Peach	6	3	42	21	5	2	2.5	5.6
Pear	9	4	57	28	9	4	2.6	5.8
Prune	3	2	42	21	3	2	1.2	2.7
Walnut	6	3	47	24	8	4	1.2	2.7
Forest residues								
Unspecified[m]	17	8	140	70	24	12	70	157
Hemlock, Douglas fir, cedar[n]	4	2	90	45	5	2		
Ponderosa pine[o]	12	6	195	98	14	7		

[a] Factors expressed as weight of pollutant emitted per weight of refuse material burned.

[b] Particulate matter from most agricultural refuse burning has been found to be in the submicrometer size range.[12]

[c] References 12 and 13 for emission factors; Reference 14 for fuel loading factors.

[d] For these refuse materials, no significant difference exists between emissions resulting from headfiring or backfiring.

[e] These factors represent emissions under typical high moisture conditions. If ferns are dried to less than 15 percent moisture, particulate emissions will be reduced by 30 percent, CO emission by 23 percent, and HC by 74 percent.

[f] When pineapple is allowed to dry to less than 20 percent moisture, as it usually is, the firing technique is not important. When headfired above 20 percent moisture, particulate emission will increase to 23 lb/ton (11.5 kg/MT) and HC will increase to 12 lb/ton (6 kg/MT). See Reference 11.

[g] This factor is for dry (<15 percent moisture) rice straw. If rice straw is burned at higher moisture levels, particulate emission will increase to 29 lb/ton (14.5 kg/MT), CO emission to 161 lb/ton (80.5 kg/MT), and HC emission to 21 lb/ton (10.5 kg/MT).

[h] See Section 6.12 for discussion of sugar cane burning.

[i] See accompanying text for definition of headfiring.

[j] See accompanying text for definition of backfiring. This category, for emission estimation purposes, includes another technique used occasionally for limiting emissions, called into-the-wind striplighting, which involves lighting fields in strips into the wind at 100-200 m (300-600 ft) intervals.

[k] Orchard prunings are usually burned in piles. No significant difference in emission results from burning a "cold pile" as opposed to using a roll-on technique, where prunings are bulldozed onto a bed of embers from a preceding fire.

[l] If orchard removal is the purpose of a burn, 30 ton/acre (66 MT/hectare) of waste will be produced.

[m] Reference 10. Nitrogen oxide emissions estimated at 4 lb/ton (2 kg/MT).

[n] Reference 15.

[o] Reference 16.

monoxide emissions. Arranging the leaves in conical piles and igniting around the periphery of the bottom proves to be the least desirable method of burning. Igniting a single spot on the top of the pile decreases the hydrocarbon and particulate emissions. Carbon monoxide emissions with top ignition decrease if moisture content is high but increase if moisture content is low. Particulate, hydrocarbon, and carbon monoxide emissions from windrow ignition (piling the leaves into a long row and igniting one end, allowing it to burn toward the other end) are intermediate between top and bottom ignition. Emission factors for leaf burning are presented in Table 2.4-3.

For more detailed information on this subject, the reader should consult the references cited at the end of this section.

Table 2.4-3. EMISSION FACTORS FOR LEAF BURNING[18,19]
EMISSION FACTOR RATING: B

Leaf species	Particulate[a,b]		Carbon monoxide[a]		Hydrocarbons[a,c]	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Black Ash	36	18	127	63.5	41	20.5
Modesto Ash	32	16	163	81.5	25	12.5
White Ash	43	21.5	113	57	21	10.5
Catalpa	17	8.5	89	44.5	15	7.5
Horse Chestnut	54	27	147	73.5	39	19.5
Cottonwood	38	19	90	45	32	16
American Elm	26	13	119	59.5	29	14.5
Eucalyptus	36	18	90	45	26	13
Sweet Gum	33	16.5	140	70	27	13.5
Black Locust	70	35	130	65	62	31
Magnolia	13	6.5	55	27.5	10	5
Silver Maple	66	33	102	51	25	12.5
American Sycamore	15	7.5	115	57.5	8	4
California Sycamore	10	5	104	52	5	2.5
Tulip	20	10	77	38.5	16	8
Red Oak	92	46	137	68.5	34	17
Sugar Maple	53	26.5	108	54	27	13.5
Unspecified	38	19	112	56	26	13

[a] These factors are an arithmetic average of the results obtained by burning high- and low-moisture content conical piles ignited either at the top or around the periphery of the bottom. The windrow arrangement was only tested on Modesto Ash, Catalpa, American Elm, Sweet Gum, Silver Maple, and Tulip, and the results are included in the averages for these species.

[b] The majority of particulates are submicron in size.

[c] Tests indicate hydrocarbons consist, on the average, of 42% olefins, 32% methane, 8% acetylene, and 13% other saturates.

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2.5 SEWAGE SLUDGE INCINERATION

By Thomas Lahre

2.5.1 Process Description [1-3]

Incineration is becoming an important means of disposal for the increasing amounts of sludge being produced in sewage treatment plants. Incineration has the advantages of both destroying the organic matter present in sludge, leaving only an odorless, sterile ash, as well as reducing the solid mass by about 90 percent. Disadvantages include the remaining, but reduced, waste disposal problem and the potential for air pollution. Sludge incineration systems usually include a sludge pretreatment stage to thicken and dewater the incoming sludge, an incinerator, and some type of air pollution control equipment (commonly wet scrubbers).

The most prevalent types of incinerators are multiple hearth and fluidized bed units. In multiple hearth units the sludge enters the top of the furnace where it is first dried by contact with the hot, rising, combustion gases, and then burned as it moves slowly down through the lower hearths. At the bottom hearth any residual ash is then removed. In fluidized bed reactors, the combustion takes place in a hot, suspended bed of sand with much of the ash residue being swept out with the flue gas. Temperatures in a multiple hearth furnace are 600°F (320°C) in the lower, ash cooling hearth; 1400 to 2000°F (760 to 1100°C) in the central combustion hearths, and 1000 to 1200°F (540 to 650°C) in the upper, drying hearths. Temperatures in a fluidized bed reactor are fairly uniform, from 1250 to 1500°F (680 to 820°C). In both types of furnace an auxiliary fuel may be required either during startup or when the moisture content of the sludge is too high to support combustion.

2.5.2 Emissions and Controls [1,2,4-7]

Because of the violent upwards movement of combustion gases with respect to the burning sludge, particulates are the major emissions problem in both multiple hearth and fluidized bed incinerators. Wet scrubbers are commonly employed for particulate control and can achieve efficiencies ranging from 95 to 99+ percent.

Although dry sludge may contain from 1 to 2 percent sulfur by weight, sulfur oxides are not emitted in significant amounts when sludge burning is compared with many other combustion processes. Similarly, nitrogen oxides, because temperatures during incineration do not exceed 1500°F (820°C) in fluidized bed reactors or 1600 to 2000°F (870 to 1100°C) in multiple hearth units, are not formed in great amounts.

Odors can be a problem in multiple hearth systems as unburned volatiles are given off in the upper, drying hearths, but are readily removed when afterburners are employed. Odors are not generally a problem in fluidized bed units as temperatures are uniformly high enough to provide complete oxidation of the volatile compounds. Odors can also emanate from the pretreatment stages unless the operations are properly enclosed.

Emission factors for sludge incinerators are shown in Table 2.5-1. It should be noted that most sludge incinerators operating today employ some type of scrubber.

Table 2.5-1. EMISSION FACTORS FOR SEWAGE SLUDGE INCINERATORS
EMISSION FACTOR RATING: B

Pollutant	Emissions[a]			
	Uncontrolled[b]		After scrubber	
	lb/ton	kg/MT	lb/ton	kg/MT
Particulate[c]	100	50	3	1.5
Sulfur dioxide[d]	1	0.5	0.8	0.4
Carbon monoxide[e]	Neg	Neg	Neg	Neg
Nitrogen oxides[d] (as NO_2)	6	3	5	2.5
Hydrocarbons[d]	1.5	0.75	1	0.5
Hydrogen chloride gas[d]	1.5	0.75	0.3	0.15

[a] Unit weights in terms of dried sludge.
[b] Estimated from emission factors after scrubbers.
[c] References 6-9.
[d] Reference 8.
[e] References 6, 8.

References for Section 2.5

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3. INTERNAL COMBUSTION ENGINE SOURCES

The internal combustion engine in both mobile and stationary applications is a major source of air pollutant emissions. Internal combustion engines were responsible for approximately 73 percent of the carbon monoxide, 56 percent of the hydrocarbons, and 50 percent of the nitrogen oxides (NO_X as NO_2) emitted during 1970 in the United States.[1] These sources, however, are relatively minor contributors of total particulate and sulfur oxides emissions. In 1970, nationwide, internal combustion sources accounted for only about 2.5 percent of the total particulate and 3.4 percent of the sulfur oxides.[1]

The three major uses for internal combustion engines are: to propel highway vehicles, to propel off-highway vehicles, and to provide power from a stationary position. Associated with each of these uses are engine duty cycles that have a profound effect on the resulting air pollutant emissions from the engine. The following sections describe the many applications of internal combustion engines, the engine duty cycles, and the resulting emissions.

DEFINITIONS USED IN CHAPTER 3

Calendar year – A cycle in the Gregorian calendar of 365 or 366 days divided into 12 months beginning with January and ending with December.

Catalytic device – A piece of emission control equipment that is anticipated to be the major component used in post 1974 light-duty vehicles to meet the Federal emission standards.

Cold vehicle operation – The first 505 seconds of vehicle operation following a 4-hour engine-off period. (for catalyst vehicles a 1-hour engine-off period).

Composite emission factor (highway vehicle) – The emissions of a vehicle in gram/mi (g/km) that results from the product of the calendar year emission rate, the speed correction factor, the temperature correction factor, and the hot/cold weighting correction factor.

Crankcase emissions – Airborne substance emitted to the atmosphere from any portion of the crankcase ventilation or lubrication systems of a motor vehicle engine.

1975 Federal Test Procecure (FTP) – The Federal motor vehicle emission test as described in the *Federal Register*, Vol. 36, Number 128, July 2, 1971.

Fuel evaporative emissions – Vaporized fuel emitted into the atmosphere from the fuel system of a motor vehicle.

Heavy-duty vehicle – A motor vehicle designated primarily for transportation of property and rated at more than 8500 pounds (3856 kilograms) gross vehicle weight (GVW) or designed primarily for transportation of persons and having a capacity of more than 12 persons.

High-altitude emission factors – Substantial changes in emission factors from gasoline-powered vehicles occur as altitude increases. These changes are caused by fuel metering enrichment because of decreasing air density. No relationship between mass emissions and altitude has been developed. Tests have been conducted at near sea level and at approximately 5000 feet (1524 meters) above sea level, however. Because most major U.S. urban areas at high altitude are close to 5000 feet (1524 meters), an arbitrary value of 3500 ft (1067 m) and above is used to define high-altitude cities.

Horsepower-hours – A unit of work.

Hot/cold weighting correction factor – The ratio of pollutant exhaust emissions for a given percentage of cold operation (w) to pollutant exhaust emissions measured on the 1975 Federal Test Procedure (20 percent cold operation) at ambient temperature (t).

Light-duty truck – Any motor vehicle designated primarily for transportation of property and rated at 8500 pounds (3856 kilograms) GVW or less. Although light-duty trucks have a load carrying capability that exceeds that of passenger cars, they are typically used primarily for personal transportation as passenger car substitutes.

Light-duty vehicle (passenger car) – Any motor vehicle designated primarily for transportation of persons and having a capacity of 12 persons or less.

Modal emission model – A mathematical model that can be used to predict the warmed-up exhaust emissions for groups of light-duty vehicles over arbitrary driving sequences.

Model year – A motor vehicle manufacturer's annual production period. If a manufacturer has no annual production period, the term "model year" means a calendar year.

Model year mix – The distribution of vehicles registered by model year expressed as a fraction of the total vehicle population.

Nitrogen oxides – The sum of the nitric oxide and nitrogen dioxide contaminants in a gas sample expressed as if the nitric oxide were in the form of nitrogen dioxide. All nitrogen oxides values in this chapter are corrected for relative humidity.

Speed correction factor – The ratio of the pollutant (p) exhaust emission factor at speed "x" to the pollutant (p) exhaust emission factor as determined by the 1975 Federal Test Procedure at 19.6 miles per hour (31.6 kilometers per hour).

Temperature correction factor – The ratio of pollutant exhaust emissions measured over the 1975 Federal Test Procedure at ambient temperature (t) to pollutant exhaust emissions measured over the 1975 Federal Test Procedure at standard temperature conditions (68 to 86°F).

Reference

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3.1 HIGHWAY VEHICLES

Passenger cars, light trucks, heavy trucks, and motorcycles comprise the four main categories of highway vehicles. Within each of these categories, powerplant and fuel variations result in significantly different emission characteristics. For example, heavy trucks may be powered by gasoline or diesel fuel or operate on a gaseous fuel such as compressed natural gas (CNG).

It is important to note that highway vehicle emission factors change with time and, therefore, must be calculated for a specific time period, normally one calendar year. The major reason for this time dependence is the gradual replacement of vehicles without emission control equipment by vehicles with control equipment, as well as the gradual deterioration of vehicles with control equipment as they accumulate age and mileage. The emission factors presented in this chapter cover only calendar years 1971 and 1972 and are based on analyses of actual tests of existing sources and control systems. Projected emission factors for future calendar years are no longer presented in this chapter because projections are "best guesses" and are best presented independently of analytical results. The authors are aware of the necessity for forecasting emissions; therefore, projected emission factors are available in Appendix D of this document.

Highway vehicle emission factors are presented in two forms in this chapter. Section 3.1.1 contains average emission factors for calendar year 1972 for selected values of vehicle miles traveled by vehicle type (passenger cars, light trucks, and heavy trucks), ambient temperature, cold/hot weighting, and average vehicle speed. The section includes one case that represents the average national emission factors as well as thirteen other scenarios that can be used to assess the sensitivity of the composite emission factor to changing input conditions. All emission factors are given in grams of pollutant per kilometer traveled (and in grams of pollutant per mile traveled).

The emission factors given in sections 3.1.2 through 3.1.7 are for individual classes of highway vehicles and their application is encouraged if specific statistical data are available for the area under study. The statistical data required include vehicle registrations by model year and vehicle type, annual vehicle travel in miles or kilometers by vehicle type and age, average ambient temperature, percentage of cold-engine operation by vehicle type, and average vehicle speed. When regional inputs are not available, national values (which are discussed) may be applied.

3.1.1 Average Emission Factors for Highway Vehicles

revised by David S. Kircher
and Marcia E. Williams

3.1.1.1 General–Emission factors presented in this section are intended to assist those individuals interested in compiling approximate mobile source emission estimates for large areas, such as an individual air quality region or the entire nation, for calendar year 1972. Projected mobile source emission factors for future years are no longer presented in this section. This change in presentation was made to assure consistency with the remainder of this publication, which contains emission factors based on actual test results on currently controlled sources and pollutants. Projected average emission factors for vehicles are available, however, in Appendix D of this publication.

The emission factor calculation techniques presented in sections 3.1.2 through 3.1.5 of this chapter are strongly recommended for the formulation of localized emission estimates required for air quality modeling or for the evaluation of air pollutant control strategies. Many factors, which vary with geographic location and estimation situation, can affect emission estimates considerably. The factors of concern include average vehicle speed, percentage of cold vehicle operation, percentage of travel by vehicle category (automobiles, light trucks, heavy trucks), and ambient temperature. Clearly, the infinite variations in these factors make it impossible to present composite mobile source emission factors for each application. An effort has been made, therefore, to present average emission factors for a range of conditions. The following conditions are considered for each of these cases:

Average vehicle speed – Two vehicle speeds are considered. The first is an average speed of 19.6 mi/hr (31.6 km/hr), which should be typical of a large percentage of urban vehicle operation. The second is an average speed of 45 mi/hr (72 km/hr), which should be typical of highway or rural operation.

Percentage of cold operation – Three percentages of cold operation are considered. The first (at 31.6 km/hr) assumes that 20 percent of the automobiles and light trucks are operating in a cold condition (representative of vehicle start-up after a long engine-off period) and that 80 percent of the automobiles and light trucks are operating in a hot condition (warmed-up vehicle operation). This condition can be expected to assess the engine temperature situation over a large area for an entire day. The second situation assumes that 100 percent of the automobiles and light trucks are operating in a hot condition (at 72 km/hr). This might be applicable to rural or highway operation. The third situation (at 31.6 km/hr) assumes that 100 percent of the automobiles and light trucks are operating in a cold condition. This might be a worst-case situation around an indirect source such as a sports stadium after an event lets out. In all three situations, heavy-duty vehicles are assumed to be operating in a hot condition.

Percentage of travel by vehicle type – Three situations are considered. The first (at both 31.6 km/hr and 72 km/hr) involves a nationwide mix of vehicle miles traveled by automobiles, light trucks, heavy gasoline trucks, and heavy diesel trucks. The specific numbers are 80.4, 11.8, 4.6, and 3.2 percent of total vehicle miles traveled, respectively.[1, 2] The second (at 31.6 km/hr) examines a mix of vehicle miles traveled that might be found in a central city area. The specific numbers are 63, 32, 2.5, and 2.5 percent, respectively. The third (31.6 km/hr) examines a mix of vehicles that might be found in a suburban location or near a localized indirect source where no heavy truck operation exist. The specific numbers are 88.2, 11.8, 0, and 0 percent, respectively.

Ambient temperature – Two situations at 31.6 km/hr are considered: an average ambient temperature of 24°C (75°F) and an average ambient temperature of 10°C (50°F).

Table 3.1.1-1 presents composite CO, HC, and NO_X factors for the 13 cases discussed above for calendar year 1972. Because particulate emissions and sulfur oxides emissions are not assumed to be functions of the factors discussed above, these emission factors are the same for all scenarios and are also presented in the table. The table entries were calculated using the techniques described and data presented in sections 3.1.2, 3.1.4, and 3.1.5 of this chapter. Examination of Table 3.1.1-1 can indicate the sensitivity of the composite emission factor to various

Table 3.1.1-1. AVERAGE EMISSION FACTORS FOR HIGHWAY VEHICLES, CALENDAR YEAR 1972
EMISSION FACTOR RATING: B

Scenario						Emission factors for highway vehicles									
Vehicle weight mix	Average route speed,		Ambient temperature,		Cold operation,	Carbon monoxide		Hydrocarbons		Nitrogen oxides		Particulate		Sulfur oxides	
	mi/hr	km/hr	°F	°C	%	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km
National average	19.6	31.6	75	24	20	76.5	47.5	10.8	6.7	4.9	3.0	0.60	0.37	0.23	0.14
			50	10	20	97.1	60.3	13.0	8.1	5.4	3.4	0.60	0.37	0.23	0.14
			75	24	100	145	90.0	14.6	9.1	4.6	2.9	0.60	0.37	0.23	0.14
			50	10	100	228	142	22.4	13.9	4.6	2.9	0.60	0.37	0.23	0.14
No heavy-duty travel	19.6	31.6	75	24	20	70.6	43.8	9.6	6.0	4.2	2.6	0.54	0.34	0.13	0.08
			50	10	20	92.9	57.7	11.3	7.0	4.7	2.9	0.54	0.34	0.13	0.08
			75	24	100	146	90.7	13.8	8.6	3.8	2.4	0.54	0.34	0.13	0.08
			50	10	100	234	145	22.1	13.7	3.8	2.4	0.54	0.34	0.13	0.08
Central City	19.6	31.6	75	24	20	78.2	48.6	11.2	7.0	4.8	3.0	0.60	0.37	0.20	0.12
			50	10	20	101	62.7	13.7	8.5	5.3	3.3	0.60	0.37	0.20	0.12
			75	24	100	154	95.6	15.6	9.7	4.5	2.8	0.60	0.37	0.20	0.12
			50	10	100	245	152	24.5	15.2	4.5	2.8	0.60	0.37	0.20	0.12
National average	45	72.5	75	24	0	29.8	18.5	4.7	2.9	8.0	5.0	0.60	0.37	0.23	0.14

conditions. A user who has specific data on the input factors should calculate a composite factor to fit the exact scenario. When specific input factor data are not available, however, it is hoped that the range of values presented in the table will cover the majority of applications. The user should be sure, however, that the appropriate scenario is chosen to fit the situation under analysis. In many cases, it is not necessary to apply the various temperature, vehicle speed, and cold/hot operation correction factors because the basic emission factors (24°C, 31.6 km/hr, 20 percent cold operation, nationwide mix of travel by vehicle category) are reasonably accurate predictors of motor vehicle emissions on a regionwide (urban) basis.

References for Section 3.1.1

1. Highway Statistics 1971. U.S. Department of Transportation. Federal Highway Administration. Washington, D.C. 1972. p. 81.

2. 1972 Census of Transportation. Truck Inventory and Use Survey. U.S. Department of Commerce. Bureau of the Census. Washington, D.C. 1974.

3.1.2 Light-Duty, Gasoline-Powered Vehicles (Automobiles)

by David S. Kircher,
Marcia E. Williams,
and Charles C. Masser

3.1.2.1 General – Because of their widespread use, light-duty vehicles (automobiles) are responsible for a large share of air pollutant emissions in many areas of the United States. Substantial effort has been expended recently to accurately characterize emissions from these vehicles.[1,2] The methods used to determined composite automobile emission factors have been the subject of continuing EPA research, and, as a result, two different techniques for estimating CO, HC, and NO_x exhaust emission factors are discussed in this section.

The first method, based on the Federal Test Procedure (FTP),[3,4] is a modification of the procedure that was discussed in this chapter in earlier editions of AP-42. The second and newer procedure, "modal" emissions analysis, enables the user to input a specific driving pattern (or driving "cycle") and to arrive at an emissions rate.[5] The modal technique driving "modes", which include idle, steady-speed cruise, acceleration, and deceleration, are of sufficient complexity that computerization was required. Because of space limitations, the computer program and documentation are not provided in this section but are available elsewhere.[5]

In addition to the methodologies presented for calculating CO, HC, and NO_x exhaust emissions, data are given later in this section for emissions in the idle mode, for crankcase and evaporative hydrocarbon emissions, and for particulate and sulfur oxides emissions.

3.1.2.2 FTP Method for Estimating Carbon Monoxide, Exhaust Hydrocarbons and Nitrogen Oxides Emission Factors – This discussion is begun with a note of caution. At the outset, many former users of this method may be somewhat surprised by the organizational and methodological changes that have occurred. Cause for concern may stem from: (1) the apparent disappearance of "deterioration" factors and (2) the apparent loss of the much-needed capability to project future emission levels. There are, however, substantive reasons for the changes implemented herein.

Results from EPA's annual surveillance programs (Fiscal Years 1971 and 1972) are not yet sufficient to yield a statistically meaningful relationship between emissions and accumulated mileage. Contrary to the previous assumption, emission deterioration can be convincingly related not only to vehicle mileage but also to vehicle age. This relationship may not come as a surprise to many people, but the complications are significant. Attempts to determine a functional relationship between *only* emissions and accumulated mileage have indicated that the data can fit a linear form as well as a non-linear (log) form. Rather than attempting to force the data into a mathematical mold, the authors have chosen to present emission factors by both model year and calendar year. The deterioration factors are, therefore, "built in" to the emission factors. This change simplifies the calculations and represents a realistic, sound use of emission surveillance data.

The second change is organizational: emission factors projected to future years are no longer presented in this section. This is in keeping with other sections of the publication, which contains emission factors only for existing sources based on analyses of test results. As mentioned earlier, projections are "best guesses" and are best presented independently of analytical results (see Appendix D).

The calculation of composite exhaust emission factors using the FTP method is given by:

$$e_{npstw} = \sum_{i=n-12}^{n} c_{ipn} \; m_{in} \; v_{ips} \; z_{ipt} \; r_{iptw} \qquad (3.1.2\text{-}1)$$

where: e_{npstw} = Composite emission factor in g/mi (g/km) for calendar year (n), pollutant (p), average speed (s), ambient temperature (t), and percentage cold operation (w)

c_{ipn} = The FTP (1975 Federal Test Procedure) mean emission factor for the i^{th} model year light-duty vehicles during calendar year (n) and for pollutant (p)

m_{in} = The fraction of annual travel by the i^{th} model year light-duty vehicles during calendar year (n)

v_{ips} = The speed correction factor for the i^{th} model year light-duty vehicles for pollutant (p) and average speed (s)

z_{ipt} = The temperature correction factor for the i^{th} model year light-duty vehicles for pollutant (p) and ambient temperature (t)

r_{iptw} = The hot/cold vehicle operation correction factor for the i^{th} model year light-duty vehicles for pollutant (p), ambient temperature (t), and percentage cold operation (w)

The data necessary to complete this calculation for any geographic area are presented in Tables 3.1.2-1 through 3.1.2-8. Each of the variables in equation 3.1.2-1 is described in greater detail below, after which the technique is illustrated by an example.

Table 3.1.2-1. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY VEHICLES –EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1971[a,b]
(BASED ON 1975 FEDERAL TEST PROCEDURE)
EMISSION FACTOR RATING: A

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1968	86.5	53.7	8.74	5.43	3.54	2.20
1968	67.8	42.1	5.54	3.44	4.34	2.70
1969	61.7	38.3	5.19	3.22	5.45	3.38
1970	47.6	29.6	3.77	2.34	5.15	3.20
1971	39.6	24.6	3.07	1.91	5.06	3.14
High altitude						
Pre-1968	126.9	78.8	10.16	6.31	1.87	1.17
1968	109.2	67.8	7.34	4.59	2.20	1.37
1969	76.4	47.4	6.31	3.91	2.59	1.61
1970	94.8	58.9	6.71	4.17	2.78	1.73
1971	88.0	54.6	5.6	3.48	3.05	1.89

[a] Note: The values in this table can be used to estimate emissions only for calendar year 1971. This reflects a substantial change over past presentation of data in this chapter (see text for details).

[b] References 1 and 2. These references summarize and analyze the results of emission tests of light-duty vehicles in several U.S. cities.

77<

Table 3.1.2-2. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY VEHICLES–STATE OF CALIFORNIA ONLY–FOR CALENDAR YEAR 1971[a,b]

(BASED ON 1975 FEDERAL TEST PROCEDURE)

EMISSION FACTOR RATING: A

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
California						
Pre-1966[c]	86.5	53.7	8.74	5.43	3.54	2.20
1966	65.2	40.5	7.84	4.87	3.40	2.11
1967	67.2	41.7	5.33	3.31	3.42	2.12
1968[c]	67.8	42.1	5.54	3.44	4.34	2.70
1969[c]	61.7	38.3	5.19	3.22	5.45	3.38
1970[c]	50.8	31.5	4.45	2.76	4.62	2.87
1971	42.3	26.3	3.02	1.88	3.83	2.38

[a] Note: The values in this table can be used to estimate emissions only for calendar year 1971. This reflects a substantial change past presentations of data in this chapter (see text for details).

[b] References 1. This reference summarizes and analyzes the results of emission tests of light-duty vehicles in Los Angeles as well as five other U.S. cities during 1971-1972.

[c] Data for these model years are mean emission test values for the five low altitude test cities summarized in Reference 1.

Table 3.1.2.-3. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY VEHICLES–EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1972[a,b]

(BASED ON 1975 FEDERAL TEST PROCEDURE)

EMISSION FACTOR RATING: A

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1968	93.5	58.1	8.67	5.38	3.34	2.07
1968	63.7	39.6	6.33	3.93	4.44	2.76
1969	64.2	39.9	4.95	3.07	5.00	3.10
1970	53.2	33.0	4.89	3.04	4.35	2.70
1971	51.1	31.7	3.94	2.45	4.30	2.67
1972	36.9	22.9	3.02	1.88	4.55	2.83
High altitude						
Pre-1968	141.0	87.6	11.9	7.39	2.03	1.26
1968	101.4	63.0	6.89	4.26	2.86	1.78
1969	97.8	60.7	5.97	3.71	2.93	1.82
1970	87.5	54.3	5.56	3.45	3.32	2.06
1971	80.3	49.9	5.19	3.22	2.74	1.70
1972	80.4	50.0	4.75	2.94	3.08	1.91

[a] Note: The values in this table can be used to estimate emissions only for calendar year 1972. This reflects a substantial change over past presentation of data in this chapter (see text for details).

[b] Reference 2. This reference summarizes and analyzes the results of emission tests of light-duty vehicles in six U.S. metropolitan areas during 1972-1973.

Table 3.1.2-4. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY VEHICLES–STATE OF CALIFORNIA ONLY–FOR CALENDAR YEAR 1972[a,b]
(BASED ON 1975 FEDERAL TEST PROCEDURE)
EMISSION FACTOR RATING: A

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
California						
Pre-1966[c]	93.5	58.1	8.67	5.38	3.34	2.07
1966	86.9	54.0	7.46	4.63	3.43	2.13
1967	75.4	46.8	5.36	3.33	3.77	2.34
1968[c]	63.7	39.6	6.33	3.93	4.44	2.76
1969[c]	64.2	39.9	4.95	3.07	5.00	3.10
1970	78.5	48.7	6.64	4.12	4.46	2.77
1971	59.7	37.1	3.98	2.47	3.83	2.38
1972	46.7	29.0	3.56	2.21	3.81	2.37

[a] Note: The values in this table can be used to estimate emissions only for calendar year 1972. This represents a substantial change over past presentation of data in this chapter (see text for details).

[b] Reference 2. This reference summarizes and analyzes the results of emission tests of light-duty vehicles in Los Angeles as well as in five other U.S. cities during 1972-1973.

[c] Data for these model years are mean emission test values for the five low altitude test cities summarized in Reference 2.

Table 3.1.2-5. SAMPLE CALCULATION OF FRACTION OF LIGHT-DUTY VEHICLE ANNUAL TRAVEL BY MODEL YEAR[a]

Age, years	1972 Fraction of total vehicles in use nationwide (a)[b]	Average annual miles driven (b)[c]	a x b	1972 Fraction of annual travel (m)[d]
1	0.083	15,900	1,320	0.116
2	0.103	15,000	1,545	0.135
3	0.102	14,000	1,428	0.125
4	0.106	13,100	1,389	0.122
5	0.099	12,200	1,208	0.106
6	0.087	11,300	983	0.086
7	0.092	10,300	948	0.083
8	0.088	9,400	827	0.072
9	0.068	8,500	578	0.051
10	0.055	7,600	418	0.037
11	0.039	6,700	261	0.023
12	0.021	6,700	141	0.012
$\geq$13	0.057	6,700	382	0.033

[a] References 6 and 7.

[b] These data are for July 1, 1972, from Reference 7 and represent the U.S. population of light-duty vehicles by model year for that year only.

[c] Mileage values are the results of at least squares analysis of data in Reference 6.

[d] $m = ab/\Sigma ab$.

Table 3.1.2-6. COEFFICIENTS FOR SPEED CORRECTION FACTORS FOR LIGHT-DUTY VEHICLES[a,b]

		$v_{ips} = e^{(A + BS + CS^2)}$						$v_{ips} = A + BS$	
		Hydrocarbons			Carbon monoxide			Nitrogen oxides	
Location	Model year	A	B	C	A	B	C	A	B
Low altitude (Excluding 1966-1967 Calif.)	1957-1967	0.953	-6.00×10^{-2}	5.81×10^{-4}	0.967	-6.07×10^{-2}	5.78×10^{-4}	0.808	0.980×10^{-2}
California	1966-1967	0.957	-5.98×10^{-2}	5.63×10^{-4}	0.981	-6.22×10^{-2}	6.19×10^{-4}	0.844	0.798×10^{-2}
Low altitude	1968	1.070	-6.63×10^{-2}	5.98×10^{-4}	1.047	-6.52×10^{-2}	6.01×10^{-4}	0.888	0.569×10^{-2}
	1969	1.005	-6.27×10^{-2}	5.80×10^{-4}	1.259	-7.72×10^{-2}	6.60×10^{-4}	0.915	0.432×10^{-2}
	1970	0.901	-5.70×10^{-2}	5.59×10^{-4}	1.267	-7.72×10^{-2}	6.40×10^{-4}	0.843	0.798×10^{-2}
	1971-1972	0.943	-5.92×10^{-2}	5.67×10^{-4}	1.241	-7.52×10^{-2}	6.09×10^{-4}	0.843	0.804×10^{-2}
High altitude	1957-1967	0.883	-5.58×10^{-2}	5.52×10^{-4}	0.721	-4.57×10^{-2}	4.56×10^{-4}	0.602	2.027×10^{-2}
	1968	0.722	-4.63×10^{-2}	4.80×10^{-4}	0.662	-4.23×10^{-2}	4.33×10^{-4}	0.642	1.835×10^{-2}
	1969	0.706	-4.55×10^{-2}	4.84×10^{-4}	0.628	-4.04×10^{-2}	4.26×10^{-4}	0.726	1.403×10^{-2}
	1970	0.840	-5.33×10^{-2}	5.33×10^{-4}	0.835	-5.24×10^{-2}	4.98×10^{-4}	0.614	1.978×10^{-2}
	1971-1972	0.787	-4.99×10^{-2}	4.99×10^{-4}	0.894	-5.54×10^{-2}	4.99×10^{-4}	0.697	1.553×10^{-2}

[a] Reference 8. Equations should not be extended beyond the range of the data (15 to 45 mi/hr; 24 to 72 km/hr). For speed correction factors at low speeds (5 and 10 mi/hr; 8 and 16 km/hr) see Table 3.1.2-7.

[b] The speed correction factor equations and coefficients presented in this table are expressed in terms of english units (miles per hour). In order to perform calculations using the metric system of units, it is suggested that kilometers per hour be first converted to miles per hour (1 km/hr = 0.621 mi/hr). Once speed correction factors are determined, all other calculations can be performed using metric units.

Table 3.1.2-7. LOW AVERAGE SPEED CORRECTION FACTORS FOR LIGHT-DUTY VEHICLES[a]

Location	Model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
		5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)	5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)	5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)
Low altitude (Excluding 1966-1967 Calif.)	1957-1967	2.72	1.57	2.50	1.45	1.08	1.03
California	1966-1967	1.79	1.00	1.87	1.12	1.16	1.09
Low altitude	1968	3.06	1.75	2.96	1.66	1.04	1.00
	1969	3.57	1.86	2.95	1.65	1.08	1.05
	1970	3.60	1.88	2.51	1.51	1.13	1.05
	1971-1972	4.15	2.23	2.75	1.63	1.15	1.03
High altitude	1957-1967	2.29	1.48	2.34	1.37	1.33	1.20
	1968	2.43	1.54	2.10	1.27	1.22	1.18
	1969	2.47	1.61	2.04	1.22	1.22	1.08
	1970	2.84	1.72	2.35	1.36	1.19	1.11
	1971-1972	3.00	1.83	2.17	1.35	1.06	1.02

[a] Driving patterns developed from CAPE-21 vehicle operation data (Reference 9) were input to the modal emission analysis model (see section 3.1.2.3). The results predicted by the model (emissions at 5 and 10 mi/hr; 8 and 16 km/hr) were divided by FTP emission factors for hot operation to obtain the above results. The above data are approximate and represent the best currently available information.

Table 3.1.2-8. LIGHT-DUTY VEHICLE TEMPERATURE CORRECTION FACTORS AND HOT/COLD VEHICLE OPERATION CORRECTION FACTORS FOR FTP EMISSION FACTORS[a]

Pollutant	Temperature correction $(z_{ipt})^b$	Hot/Cold operation correction $[f(t)]^b$
Carbon monoxide	$-0.0127\,t + 1.95$	$0.0045\,t + 0.02$
Hydrocarbons	$-0.0113\,t + 1.81$	$0.0079\,t + 0.03$
Nitrogen oxides	$-0.0046\,t + 1.36$	$-0.0068\,t + 1.64$

[a] Reference 10. Temperature (t) is expressed in °F. In order to apply these equations, °C must be first converted to °F. The appropriate conversion formula is: $F=(9/5)C + 32$. For temperatures expressed on the Kelvin (K) scale: $F=9/5(K-273.16) + 32$.

[b] The formulae for z_{ipt} enable the correction of the FTP emission factors for ambient temperature effects only. The amount of cold/hot operation is not affected. The formulae for f(t), on the other hand, are part of equation 3.1.2-2 for calculating r_{iptw}. The variable r_{iptw} corrects for cold/hot operation as well as ambient temperature.

Note: z_{ipt} can be applied without r_{iptw}, but not vica versa.

FTP emission factor (c_{ipn}). The results of the first two EPA annual light-duty vehicle surveillance programs are summarized in Tables 3.1.2-1 through 3.1.2-4. These data for calendar years 1971 and 1972 are divided by geographic area into: low altitude (excluding California), high altitude (excluding California), and California only. California emission factors are presented separately because, for several model years, California vehicles have been subject to emission standards that differ from standards applicable to vehicles under the Federal emission control program. For those model year vehicles for which California did not have separate emission standards, the national emission factors are assumed to apply in California as well. Emissions at high altitude are differentiated from those at low altitude to account for the effect that altitude has on air-fuel ratios and concomitant emissions. The tabulated values are applicable to calendar years 1971 and 1972 for each model year.

Fraction of annual travel by model year (m_i). A sample calculation of this variable is presented in Table 3.1.2-5. In the example, nationwide statistics are used, and the fraction of in-use vehicles by model year (vehicle age) is weighted on the basis of the annual miles driven. The calculation may be "localized" to reflect local (county, state, etc.) vehicle age mix, annual miles driven, or both. Otherwise, the national data can be used. The data presented in Table 3.1.2-5 are for calendar year 1972 only; for later calendar years, see Appendix D.

Speed Correction Factors (v_{ips}). Speed correction factors enable the "adjustment" of FTP emission factors to account for differences in average route speed. Because the implicit average route speed of the FTP is 19.6 mi/hr (31.6 km/hr), estimates of emissions at higher or lower average speeds require a correction.

It is important to note the difference between "average route speed" and "steady speed". Average route speed is trip-related and based on a composite of the driving modes (idle, cruise, acceleration, deceleration) encountered, for example, during a typical home-to-work trip. Steady speed is highway facility-oriented. For instance, a group of vehicles traveling over an uncongested freeway link (with a volume to capacity ratio of 0.1, for example) might be traveling at a steady speed of about 55 mi/hr (89 km/hr). Note, however, that steady speeds, even at the link level, are unlikely to occur where resistance to traffic flow occurs (unsynchronized traffic signaling, congested flow, etc.)

In previous revisions to this section, the limited data available for correcting for average speed were presented graphically. Recent research, however, has resulted in revised speed relationships by model year.[8] To facilitate the presentation, the data are given as equations and appropriate coefficients in Table 3.1.2-6. These relationships were developed by performing five major tasks. First, urban driving pattern data collected during the CAPE-10 Vehicle Operations Survey[11] were processed by city and time of day into freeway, non-freeway, and composite speed-mode matrices. Second, a large number of driving patterns were computer-generated for a range of average speeds (15 to 45 mi/hr; 24 to 72 km/mi) using weighted combinations of freeway and non-freeway matrices. Each of these patterns was filtered for "representativeness." Third, the 88 resulting patterns were input (second-by-second speeds) to the EPA modal emission analysis model (see sections 3.1.2.3). The output of the model was estimated emissions for each pattern of 11 vehicle groups (see Table 3.1.2.6 for a listing of these groups). Fourth, a regression analysis was performed to relate estimated emissions to average route speed for each of the 11 vehicle groups. Fifth, these relationships were normalized to 19.6 mi/hr (31.6 km/hr) and summarized in Table 3.1.2-6.

The equations in Table 3.1.2-6 apply only for the range of the data – from 15 to 45 mi/hr (24 to 72 km/hr). Because there is a need, in some situations, to estimate emissions at very low average speeds, correction factors for 5 and 10 mi/hr (8 and 16 km/hr) presented in Table 3.1.2-7 were developed using a method somewhat like that described above, again using the modal emission model. The modal emission model predicts emissions from warmed-up vehicles. The use of this model to develop speed correction factors makes the assumption that a given speed correction factor applies equally well to hot and cold vehicle operation. Estimation of warmed-up idle emissions are presented in section 3.1.2.4 on a gram per minute basis.

Temperature Correction Factor (z_{ipt}). The 1975 FTP requires that emissions measurements be made within the limits of a relatively narrow temperature band (68 to 86°F). Such a band facilitates uniform testing in laboratories without requiring extreme ranges of temperature control. Present emission factors for motor vehicles are based on data from the standard Federal test (assumed to be at 75°F). Recently, EPA and the Bureau of Mines undertook a test program to evaluate the effect of ambient temperature on motor vehicle exhaust emission levels.[10] The study indicates that changes in ambient temperature result in significant changes in emissions during cold start-up operation. Because many Air Quality Control Regions have temperature characteristics differing considerably from the 68 to 86°F range, the temperature correction factor should be applied. These correction factors, which can be applied between 20 and 80°F, are presented in Table 3.1.2-8. For temperatures outside this range, the appropriate endpoint correction factor should be applied.

Hot/Cold Vehicle Operation Correction Factor (r_{iptw}). The 1975 FTP measures emissions during: a cold transient phase (representative of vehicle start-up after a long engine-off period), a hot transient phase (representative of vehicle start-up after a short engine-off period), and a stabilized phase (representative of warmed-up vehicle operation). The weighting factors used in the 1975 FTP are 20 percent, 27 percent, and 53 percent of total miles (time) in each of the three phases, respectively. Thus, when the 1975 FTP emission factors are applied to a given region for the purpose of accessing air quality, 20 percent of the light-duty vehicles in the area of interest are assumed to be operating in a cold condition, 27 percent in a hot start-up condition, and 53 percent in a hot stabilized condition. For non-catalyst equipped vehicles (all pre-1975 model year vehicles), emissions in the two hot phases are essentially equivalent on a grams per mile (grams per kilometer basis). Therefore, the 1975 FTP emission factor represents 20 percent cold operation and 80 percent hot operation.

Many situations exist in which the application of these particular weighting factors may be inappropriate. For example, light-duty vehicle operation in the center city may have a much higher percentage of cold operation during the afternoon peak when work-to-home trips are at a maximum and vehicles have been standing for 8 hours. The hot/cold vehicle operation correction factor allows the cold operation phase to range from 0 to 100 percent of total light-duty vehicle operations. This correction factor is a function of the percentage of cold operation (w) and the ambient temperature (t). The correction factor is:

$$r_{iptw} = \frac{w + (100-w)\ f(t)}{20 + 80f(t)} \qquad (3.1.2\text{-}2)$$

where: f(t) is given in Table 3.1.2-8.

Sample Calculation. As a means of further describing the application of equation 3.1.2-1, calculation of the carbon monoxide composite emission factor is provided as an example. To perform this calculation (or any calculation using this procedure), the following questions must be answered:

1. What calendar year is being considered?
2. What is the average vehicle speed in the area of concern?
3. Is the area at low altitude (non-California), in California, or at high altitude?
4. Are localized vehicle mix and/or annual travel data available?
5. Which pollutant is to be estimated? (For non-exhaust hydrocarbons see section 3.1.2.5).
6. What is the ambient temperature (if it does not fall within the 68 to 86°F Federal Test Procedure range)?
7. What percentage of vehicle operation is cold operation (first 500 seconds of operation after an engine-off period of at least 4 hours)?

For this example, the composite carbon monoxide emission factor for 1972 will be estimated for a hypothetical county. Average vehicle speed for the county is assumed to be 30 mi/hr. The county is at low altitude (non-California), and localized vehicle mix/annual travel data are unavailable (nationwide statistics are to be used). The ambient temperature is assumed to be 50°F and the percentage of cold vehicle operation is assumed to be 40 percent. To simplify the presentation, the appropriate variables are entered in the following tabulation.

83<

Model year(s)			Variables,[a]			$(c_{ipn})(m_{in})(v_{ips})$ $(z_{ipt})(r_{iptw})$
	c_{ipn}	m_{in}	v_{ips}	z_{ipt}	r_{iptw}	
Pre-1968	58.1	0.396	0.72	1.315	1.39	30.3
1968	39.6	0.106	0.69	1.315	1.39	5.3
1969	39.9	0.122	0.63	1.315	1.39	5.6
1970	33.0	0.125	0.62	1.315	1.39	4.7
1971	31.7	0.135	0.63	1.315	1.39	4.9
1972	22.9	0.116	0.63	1.315	1.39	3.1
						e_{npstw} = 53.9 g/km

[a] The variable c_{ipn} above is from Table 3.1.2-3, and the variable m_{in} was taken from the sample calculation based on nationwide data, Table 3.1.2-5. The fraction of travel for pre-1968 (6 years old and older) vehicles is the sum of the last eight values in the far right-hand column of the table. The speed correction factor (v_{ips}) was calculated from the appropriate equations in Table 3.1.2-6. The variable z_{ipt} was calculated from the appropriate equation in Table 3.1.2-8. The variable r_{iptw} was calculated using an equation from Table 3.1.2-8 and equation 3.1.2-2.

The resultant composite carbon monoxide emission factor for 1972 for the hypothetical county is 53.9 g/km.

3.1.2.3 Modal Emission Model for Estimating Carbon Monoxide, Hydrocarbons, and Nitrogen Oxides Emission Factors – The modal emission model and allied computer programs permit an analyst to calculate mass emission quantities of carbon monoxide, hydrocarbons, and nitrogen oxides emitted by individual vehicles or groups of vehicles over any specified driving sequence or pattern. The complexity of the model and accompanying computer programs makes presentation of the entire procedure in this publication impractical. Instead, the capabilities and limitations of the model are briefly described in the following paragraphs with the details to be found in a separate report, *Automobile Exhaust Emission Modal Analysis Model.*[5]

The modal emission model was developed because of the well-established fact that emission rates for a particular vehicle depend upon the manner in which it is operated. Stated another way, the emissions from a particular vehicle are a function of the time it spends in each of four general operating modes (idle, cruise, deceleration, acceleration) as well as specific operation within each of the four modes. In many situations, use of the basic FTP emission factors may be sufficient. Certainly, nationwide, statewide, and county-wide emission estimates that involve spatial aggregation of vehicular travel data lend themselves to the FTP method (section 3.1.2.2). There are, however, a relatively large number of circumstances for which an analyst may require emission estimates at a zonal or link level of aggregation. The analyst, for example, may be faced with providing inputs to a carbon monoxide dispersion model, estimating the impact of an indirect source (sports complex, shopping center, etc.), or preparing a highway impact statement. In such instances, the resources may be available to determine the necessary inputs to the modal model either by estimation or field studies. These data are input to the modal model and emission estimates are output.

Although the computer software package is sufficiently flexible to accept any set of input modal emission data, EPA data based on tests of 1020 individual light-duty vehicles (automobiles) that represent variations in model year, manufacture, engine and drive train equipment, accumulated mileage, state of maintenance, attached pollution abatement devices, and geographic location are a part of the package. The user, therefore, need not input any modal emission data. He inputs the driving sequence desired as speed (mi/hr) versus time (sec) in 1-second intervals and specifies the vehicle mix for which emission estimates are desired (vehicles are grouped by model year and geographic location). The output of the model can then be combined with the appropriate traffic volume for the desired time period to yield an emission estimate. The use of the modal emission model to estimate a composite emission factor does not, however, eliminate the need for temperature and cold/hot weighting correction factors. The model predicts emissions from warmed-up vehicles at an ambient temperature of approximately 75°F. The estimate of composite exhaust emission factors using the modal emission model is given by:

$$e_{ptw} = c_p \, a_{pt} \, b_{ptw} \qquad (3.1.2\text{-}3)$$

where: e_{ptw} = Composite emission factor in grams per mile (g/km) for calendar year 1971, pollutant (p), ambient temperature (t), percentage cold operation (w), and the specific driving sequence and vehicle mix specified

c_p = The mean emission factor for pollutant (p) for the specified vehicle mix and driving sequence

a_{pt} = The temperature correction factor for pollutant (p) and temperature (t) for warmed-up operation

b_{ptw} = The hot/cold vehicle operation correction factor for pollutant (p), temperature (t), and percentage cold operation (w)

The data necessary to compute a_{pt} and b_{ptw} are given in Table 3.1.2-9. The modal analysis computer program is necessary to compute c_p.[5]

Table 3.1.2-9. LIGHT-DUTY VEHICLE MODAL EMISSION MODEL CORRECTION FACTORS FOR TEMPERATURE AND COLD/HOT START WEIGHTING[a]

Pollutant	Temperature correction (a_{pt})	Hot/cold temperature correction [f(t)]
Carbon monoxide	1.0	0.0045 t + 0.02
Hydrocarbons	1.0	0.0079 t + 0.03
Nitrogen oxides	-0.0065 t + 1.49	-0.0068 t + 1.64

[a] Reference 10. Temperature is expressed in °F. In order to apply these equations, convert °C to °F (F=9/5C + 32); or °K to °F (F=9/5(K-273.16) + 32).

Temperature Correction Factor (a_{pt}). The modal analysis model predicts emissions at approximately 75°F. The temperature correction factors are expressed in equational form and presented in Table 3.1.2-9.

Hot/Cold Vehicle Operation Correction Factor (b_{ptw}). The modal analysis model predicts emissions during warmed-up vehicle operation, but there are many urban situations for which this assumption is not appropriate. The hot/cold vehicle operation correction factor allows for the inclusion of a specific percentage of cold operation. This correction factor is a function of the percentage of cold operation (w) and the ambient temperature (t). The correction factor is:

$$b_{ptw} = \frac{w + (100\text{-}w)f(t)}{100\,f(t)} \qquad (3.1.2\text{-}4)$$

where: f(t) is given in Table 3.1.2-9.

It is important that potential users of modal analysis recognize of the important limitations of the model. Although the model provides the capability of predicting emission estimates for any driving pattern, it can only predict emissions for the vehicle groups that have been tested. Presently this capability is limited to 1971 and older light-duty vehicles. Efforts are underway to add additional model years (1972-1974), and new models will be tested as they become available. Although the model is not directly amenable to projecting future year emissions, it can predict "base" year emissions. Future year emissions can be estimated using the ratio of future year to base year emissions based on FTP composite emission factors. Finally, the technique requires the input of a driving sequence and the use of a computer, and is therefore, more complex and more costly to use than the simple FTP technique (section 3.1.2.1).

The modal procedure discussion in this section is recommended when the user is interested in comparing emissions over several different specific driving scenarios. Such an application will result in more accurate comparisons than can be obtained by the method given in section 3.1.2.2. For other applications where average speed is all that is known or when calendar year to calendar year comparisons are required, the method in section 3.1.2.2 is recommended.

3.1.2.4 Carbon Monoxide, Hydrocarbon, and Nitrogen Oxides Idle Emission Factors – Estimates of emissions during a vehicles' idle operating mode may be appropriate at trip attractions such as shopping centers, airports, sports complexes, etc. Because idle emission factors are expressed (by necessity) in terms of elapsed time, emissions at idle can be estimated using vehicle operating minutes rather than the conventional vehicle miles of travel.

Application of the idle values (Table 3.1.2-10) requires calculation of a composite idle emission factor (c_p) through the use of the variable m_{in}(see section 3.1.2.2) and i_{ip} (idle pollutant p emission factor for the i^{th} model year). The temperature and hot/cold weighting factors presented in Table 3.1.2-9 apply to idle emissions. The tabulated values are based on warmed-up emissions. (For a_{pt}, see Table 3.1.2-9; for b_{ptw}, see Table 3.1.2-9 and equation 3.1.2-4.)

Table 3.1.2-10. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EMISSION FACTORS FOR LIGHT-DUTY VEHICLES IN WARMED-UP IDLE MODE[a]
(grams/minute)

Location and model year(s)	Carbon monoxide	Exhaust hydrocarbons	Nitrogen oxides
Low altitude			
Pre-1968	16.9	1.63	0.08
1968	15.8	1.32	0.12
1969	17.1	1.17	0.12
1970	13.1	0.73	0.13
1971	13.0	0.63	0.11
High altitude			
Pre-1968	18.6	1.83	0.11
1968	16.8	1.09	0.11
1969	16.6	0.90	0.10
1970	16.6	1.13	0.11
1971	16.9	0.80	0.16
California only (low altitude)			
Pre-1966	16.9	1.63	0.08
1966	18.7	1.27	0.07
1967	18.7	1.27	0.07
1968	15.8	1.32	0.12
1969	17.1	1.17	0.12
1970	19.3	0.76	0.28
1971	13.3	0.78	0.18

[a] Reference 12.

The mathematical expression is simply:

$$c_p = \sum_{i=n-12}^{n} i_{ip} \; m_{in} \; a_{pt} \; b_{ptw} \qquad (3.1.2\text{-}5)$$

Because the idle data are from the same data base used to develop the modal analysis procedure, they are subject to the same limitations. Most importantly, idle values cannot be directly used to estimate future emissions.

3.1.2.5 Crankcase and Evaporative Hydrocarbon Emission Factors – In addition to exhaust emission factors, the calculation of hydrocarbon emission from gasoline motor vehicles involves evaporative and crankcase hydrocarbon emission factors. Composite crankcase emissions can be determined using:

$$f_n = \sum_{i=n-12}^{n} h_i \; m_{in} \qquad (3.1.2\text{-}6)$$

where: f_n = The composite crankcase hydrocarbon emission factor for calendar year (n)

h_i = The crankcase emission factor for the i^{th} model year

m_{in} = The weighted annual travel of the i^{th} year during calendar year (n)

Crankcase hydrocarbon emission factor by model year are summarized in Table 3.1.2-11.

The two major sources of evaporative hydrocarbon emissions from light-duty vehicles are the fuel tank and the carburetor system. Diurnal changes in ambient temperature result in expansion of the air-fuel mixture in a partially filled fuel tank. As a result, gasoline vapor is expelled to the atmosphere. Running losses from the fuel tank occur as the fuel is heated by the road surface during driving, and hot-soak losses from the carburetor system occur after engine shut down at the end of a trip. These carburetor losses are from locations such as: the

Table 3.1.2-11. CRANKCASE HYDROCARBON EMISSIONS BY MODEL YEAR FOR LIGHT-DUTY VEHICLES EMISSION FACTOR RATING: B

Model year	Hydrocarbons g/mi	Hydrocarbons g/km
California only		
Pre-1961	4.1	2.5
1961 through 1963	0.8	0.5
1964 through 1967	0.0	0.0
Post-1967	0.0	0.0
All areas except California		
Pre-1963	4.1	2.5
1963 through 1967	0.8	0.5
Post-1967	0.0	0.0

[a] Reference 13.

carburetor vents, the float bowl, and the gaps around the throttle and choke shafts. Because evaporative emissions are a function of the diurnal variation in ambient temperature and the number of trips per day, emissions are best calculated in terms of evaporative emissions per day per vehicle. Emissions per day can be converted to emissions per mile (if necessary) by dividing by an average daily miles per vehicle value. This value is likely to vary from location to location, however. The composite evaporative hydrocarbon emission factor is given by:

$$e_n = \sum_{i=n-12}^{n} (g_i + k_i d)\ (m_i) \qquad (3.1.2\text{-}7)$$

where: e_n = The composite evaporative hydrocarbon emission factor for calendar year (n) in lb/day (g/day)

g_i = The diurnal evaporative hydrocarbon emission factor for model year (i) in lb/day (g/day)

k_i = The hot soak evaporative emission factor in lb/trip (g/trip) for the i^{th} model year

d = The number of daily trips per vehicle (3.3 trips/vehicle-day is the nationwide average)

m_i = The fraction of annual travel by the i^{th} model year during calendar year n

The variables g_i and k_i are presented in Table 3.1.2-12 by model year.

Table 3.1.2-12. EVAPORATIVE HYDROCARBON EMISSION FACTORS BY MODEL YEAR FOR LIGHT-DUTY VEHICLES[a]
EMISSION FACTOR RATING: A

Location and model year	By source[b]		Composite emissions[c]		
	Diurnal, g/day	Hot soak, g/trip	g/day	g/mi	g/km
Low altitude					
Pre-1970	26.0	14.7	74.5	2.53	1.57
1970 (Calif.)	16.3	10.9	52.3	1.78	1.11
1970 (non-Calif.)	26.0	14.7	74.5	2.53	1.57
1971	16.3	10.9	52.3	1.78	1.11
1972	12.1	12.0	51.7	1.76	1.09
High altitude[d]					
Pre-1971	37.4	17.4	94.8	3.22	2.00
1971-1972	17.4	14.2	64.3	2.19	1.36

[a] References 1, 14 and 15.

[b] See text for explanation.

[c] Gram per day values are diurnal emissions plus hot soak emisssions multiplied by the average number of trips per day. Nationwide data from References 16 and 17 indicate that the average vehicle is used for 3.3 trips per day. Gram per mile values were determined by dividing average g/day by the average nationwide travel per vehicle (29.4 mi/day) from Reference 16.

[d] Vehicles without evaporative control were not tested at high altitude. Values presented here are the product of the ratio of pre-1971 (low altitude) evaporative emissions [illegible] 1972 evaporative emissions and 1971-1972 high altitude emissions.

3.1.2.6 Particulate and Sulfur Oxide Emissions – Light-duty, gasoline-powered vehicles emit relatively small quantities of particulate and sulfur oxides in comparison with the emissions of the three pollutants discussed above. For this reason, average rather than composite emission factors should be sufficiently accurate for approximating particulate and sulfur oxide emissions from light-duty, gasoline-powered vehicles. Average emission factors for these pollutants are presented in Table 3.1.2-13. No Federal standards for these two pollutants are presently in effect, although many areas do have opacity (antismoke) regulations applicable to motor vehicles.

Table 3.1.2-13. PARTICULATE AND SULFUR OXIDES EMISSION FACTORS FOR LIGHT-DUTY VEHICLES
EMISSION FACTOR RATING: C

Pollutant	Emissions for Pre-1973 vehicles	
	g/mi	g/km
Particulate[a]		
Exhaust	0.34	0.21
Tire wear	0.20	0.12
Sulfur oxides[b] (SO_x as SO_2)	0.13	0.08

[a] References 18, 19, and 20.

[b] Based on an average fuel consumption of 13.6 mi/gal (5.8 km/liter) from Reference 21 and on the use of a fuel with a 0.032 percent sulfur content from References 22 through 24 and a density of 6.1 lb/gal (0.73 kg/liter) from References 22 and 23.

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3.1.3 Light-Duty, Diesel-Powered Vehicles

by David S. Kircher

3.1.3.1 General – In comparison with the conventional, "uncontrolled," gasoline-powered, spark-ignited, automotive engine, the uncontrolled diesel automotive engine is a low pollution powerplant. In its uncontrolled form, the diesel engine emits (in grams per mile) considerably less carbon monoxide and hydrocarbons and somewhat less nitrogen oxides than a comparable uncontrolled gasoline engine. A relatively small number of light-duty diesels are in use in the United States.

3.1.3.2 Emissions – Carbon monoxide, hydrocarbons, and nitrogen oxides emission factors for the light-duty, diesel-powered vehicle are shown in Table 3.1.3-1. These factors are based on tests of several Mercedes 220D automobiles using a slightly modified version of the Federal light-duty vehicle test procedure.[1,2] Available automotive diesel test data are limited to these results. No data are available on emissions versus average speed. Emissions from light-duty diesel vehicles during a calendar year (n) and for a pollutant (p) can be approximately calculated using:

$$e_{np} = \sum_{i=n-12}^{n} c_{ipn} \, m_{in} \qquad (3.1.2\text{-}1)$$

where: e_{np} = Composite emission factor in grams per vehicle mile for calendar year (n) and pollutant (p)

c_{ipn} = The 1975 Federal test procedure emission rate for pollutant (p) in grams/mile for the i^{th} model year at calendar year (n) (Table 3.1.3-1)

m_{in} = The fraction of total light-duty diesel vehicle miles driven by the i^{th} model year diesel light-duty vehicles

Details of this calculation technique are discussed in section 3.1.2.

The emission factors in Table 3.1.3-1 for particulates and sulfur oxides were developed using an average sulfur content fuel in the case of sulfur oxides and the Dow Measuring Procedure on the 1975 Federal test cycle for particulate.[1,6]

Table 3.1.3-1. EMISSION FACTORS FOR LIGHT-DUTY, DIESEL-POWERED VEHICLES
EMISSION FACTOR RATING: B

	Emission factors, Pre-1973 model years	
Pollutant	g/mi	g/km
Carbon monoxide[a]	1.7	1.1
Exhaust hydrocarbons	0.46	0.29
Nitrogen oxides[a,b] (NO_x as NO_2)	1.6	0.99
Particulate[b]	0.73	0.45
Sulfur oxides[c]	0.54	0.34

[a] Estimates are arithmetic mean of tests of vehicles, References 3 through 5 and 7.

[b] Reference 4.

[c] Calculated using the fuel consumption rate reported in Reference 7 and assuming the use of a diesel fuel containing 0.20 percent sulfur.

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3.1.4 Light-Duty, Gasoline-Powered Trucks and Heavy-Duty, Gasoline-Powered Vehicles

by David S. Kircher
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3.1.4.1 General – This vehicle category consists of trucks and buses powered by gasoline-fueled, spark-ignited internal combustion engines that are used both for commercial purposes (heavy trucks and buses) and personal transportation (light trucks). In addition to the use classification, the categories cover different gross vehicle weight (GVW) ranges. Light trucks range from 0 to 8500 pounds GVW (0 to 3856 kg GVW); heavy-duty vehicles have GVWs of 8501 pounds (3856 kg) and over. The light-duty truck, because of its unique characteristics and usage, is treated in a separate category in this revision to AP-42. Previously, light trucks with a GVW of 6000 pounds (2722 kg) or less were included in section 3.1.2 (Light-Duty, Gasoline-Powered Vehicles), and light trucks with a GVW of between 6001 and 8500 pounds (2722-3855 kg) were included in section 3.1.4 (Heavy-Duty, Gasoline-Powered Vehicles).

3.1.4.2 Light-Duty Truck Emissions – Because of many similarities to the automobile, light truck emission factor calculations are very similar to those presented in section 3.1.2. The most significant difference is in the Federal Test Procedure emission rate.

3.1.4.2.1. Carbon monoxide, hydrocarbon and nitrogen oxides emissions – The calculation of composite exhaust emission factors using the FTP method is given by:

$$e_{npstw} = \sum_{i=n-12}^{n} c_{ipn}\, m_{in}\, v_{ips}\, z_{ipt}\, r_{iptw} \qquad (3.1.4\text{-}1)$$

where: e_{npstw} = Composite emission factor in g/mi (g/km) for calendar year (n), pollutant (p), average speed (s), ambient temperature (t), and percentage cold operation (w)
c_{ipn} = The FTP (1975 Federal Test Procedure) mean emission factor for the i_{th} model year light-duty trucks during calendar year (n) and for pollutant (p)
m_{in} = The fraction of annual travel by the i^{th} model year light-duty trucks during calendar year (n)
v_{ips} = The speed correction factor for the i^{th} model year light-duty trucks for pollutant (p) and average speed (s)
z_{ipt} = The temperature correction for the i^{th} model year light-duty trucks for pollutant (p) and ambient temperature (t)
r_{iptw} = The hot/cold vehicle operation correction factor for the i_{th} model year light-duty trucks for pollutant (p), ambient temperature (t), and percentage of cold operation (w)

The data necessary to complete this calculation for any geographic area are presented in Tables 3.1.4-1 through 3.1.4-5. Each of the variables in equation 3.1.4-1 is described in greater detail below. The technique is illustrated, by example, in section 3.1.2.

Table 3.1.4-1. EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED TRUCKS FOR CALENDAR YEAR 1972
EMISSION FACTOR RATING: B

Location	Model year	Carbon monoxide		Exhaust hydrocarbons		Nitrogen oxides	
		g/mi	g/km	g/mi	g/km	g/mi	g/km
All areas except high altitude and California[a]	Pre-1968[a]	125	77.6	17.0	10.6	4.2	2.6
	1968	66.5	41.3	7.1	4.4	4.9	3.0
	1969	64.3	39.9	5.3	3.3	5.3	3.3
	1970	53.5	33.2	4.8	3.0	5.2	3.2
	1971	53.5	33.2	4.2	2.6	5.2	3.2
	1972	42.8	26.6	3.4	2.1	5.3	3.3
High altitude[b]	Pre-1968	189	117	23.3	14.5	2.6	1.6
	1968	106	65.8	9.7	6.0	3.2	2.0
	1969	98.0	60.9	6.4	4.0	3.1	1.9
	1970	88.0	54.6	5.5	3.4	4.0	2.5
	1971	84.1	52.2	5.5	3.4	3.3	2.0
	1972	84.1	52.2	5.3	3.3	3.6	2.2

[a] References 1 through 4. California emission factors can be estimated as follows:

1. Use pre-1968 factors for all pre-1966 California light trucks.
2. Use 1968 factors for all 1966-1968 California light trucks.
3. For 1969-1972, use the above values multiplied by the ratio of California LDV emission factors to low altitude LDV emission factors (see section 3.1.2).

[b] Based on light-duty emission factors at high altitude compared with light-duty emission factors at low altitude (section 3.1.2).

Table 3.1.4-2. COEFFICIENTS FOR SPEED ADJUSTMENT CURVES FOR LIGHT-DUTY TRUCKS[a]

Location	Model year	$v_{ips} = e^{(A + BS + CS^2)}$						$v_{ips} = A + BS$	
		Hydrocarbons			Carbon monoxide			Nitrogen oxides	
		A	B	C	A	B	C	A	B
Low altitude (Excluding 1966-1967 Calif.)	1957-1967	0.953	-6.00×10^{-2}	5.81×10^{-4}	0.967	-6.07×10^{-2}	5.78×10^{-4}	0.808	0.980×10^{-2}
California	1966-1967	0.957	-5.98×10^{-2}	5.63×10^{-4}	0.981	-6.22×10^{-2}	6.19×10^{-4}	0.844	0.798×10^{-2}
Low altitude	1968	1.070	-6.63×10^{-2}	5.98×10^{-4}	1.047	-6.52×10^{-2}	6.01×10^{-4}	0.888	0.569×10^{-2}
	1969	1.005	-6.27×10^{-2}	5.80×10^{-4}	1.259	-7.72×10^{-2}	6.60×10^{-4}	0.915	0.432×10^{-2}
	1970	0.901	-5.70×10^{-2}	5.59×10^{-4}	1.267	-7.72×10^{-2}	6.40×10^{-4}	0.843	0.798×10^{-2}
	1971-1972	0.943	-5.92×10^{-2}	5.67×10^{-4}	1.241	-7.52×10^{-2}	6.09×10^{-4}	0.843	0.804×10^{-2}
High altitude	1957-1967	0.883	-5.58×10^{-2}	5.52×10^{-4}	0.721	-4.57×10^{-2}	4.56×10^{-4}	0.602	2.027×10^{-2}
	1968	0.722	-4.63×10^{-2}	4.80×10^{-4}	0.662	-4.23×10^{-2}	4.33×10^{-4}	0.642	1.835×10^{-2}
	1969	0.706	-4.55×10^{-2}	4.84×10^{-4}	0.628	-4.04×10^{-2}	4.26×10^{-4}	0.726	1.403×10^{-2}
	1970	0.840	-5.33×10^{-2}	5.33×10^{-4}	0.835	-5.24×10^{-2}	4.98×10^{-4}	0.614	1.978×10^{-2}
	1971-1972	0.787	-4.99×10^{-2}	4.99×10^{-4}	0.894	-5.54×10^{-2}	4.99×10^{-4}	0.697	1.553×10^{-2}

[a] Reference 5. Equations should not be extended beyond the range of data (15 to 45 mi/hr). These data are for light-duty vehicles and are assumed applicable to light-duty trucks.

Table 3.1.4-3. LOW AVERAGE SPEED CORRECTION FACTORS FOR LIGHT-DUTY TRUCKS[a]

Location	Model year	Carbon monoxide 5 mi/hr (8 km/hr)	Carbon monoxide 10 mi/hr (16 km/hr)	Hydrocarbons 5 mi/hr (8 km/hr)	Hydrocarbons 10 mi/hr (16 km/hr)	Nitrogen oxides 5 mi/hr (8 km/hr)	Nitrogen oxides 10 mi/hr (16 km/hr)
Low altitude (Excluding 1966-1967 Calif.)	1957-1967	2.72	1.57	2.50	1.45	1.08	1.03
California	1966-1967	1.79	1.00	1.87	1.12	1.16	1.09
Low altitude	1968	3.06	1.75	2.96	1.66	1.04	1.00
	1969	3.57	1.86	2.95	1.65	1.08	1.05
	1970	3.60	1.88	2.51	1.51	1.13	1.05
	1971-1972	4.15	2.23	2.75	1.63	1.15	1.03
High altitude	1957-1967	2.29	1.48	2.34	1.37	1.33	1.20
	1968	2.43	1.54	2.10	1.27	1.22	1.18
	1969	2.47	1.61	2.04	1.22	1.22	1.08
	1970	2.84	1.72	2.35	1.36	1.19	1.11
	1971-1972	3.00	1.83	2.17	1.35	1.06	1.02

[a] Driving patterns developed from CAPE-21 vehicle operation data (Reference 6) were input to the modal emission analysis model (see section 3.1.2.3). The results predicted by the model (emissions at 5 and 10 mi/hr; 8 and 16 km/hr) were divided by FTP emission factors for hot operation to obtain the above results. The above data are approximate and represent the best currently available information.

Table 3.1.4-4. SAMPLE CALCULATION OF FRACTION OF ANNUAL LIGHT-DUTY TRUCK TRAVEL BY MODEL YEAR[a]

Age, years	Fraction of total vehicles in use nationwide (a)[b]	Average annual miles driven (b)	a x b	Fraction of annual travel (m)[c]
1	0.061	15,900	970	0.094
2	0.095	15,000	1,425	0.138
3	0.094	14,000	1,316	0.127
4	0.103	13,100	1,349	0.131
5	0.083	12,200	1,013	0.098
6	0.076	11,300	859	0.083
7	0.076	10,300	783	0.076
8	0.063	9,400	592	0.057
9	0.054	8,500	459	0.044
10	0.043	7,600	327	0.032
11	0.036	6,700	241	0.023
12	0.024	6,700	161	0.016
≥ 13	0.185	4,500	832	0.081

[a] Vehicles in use by model year as of 1972 (Reference 7).
[b] References 7 and 8.
[c] $m = ab/\Sigma ab$.

Table 3.1.4-5. LIGHT-DUTY TRUCK TEMPERATURE CORRECTION FACTORS AND HOT/COLD VEHICLE OPERATION CORRECTION FACTORS FOR FTP EMISSION FACTORS[a]

Pollutant	Temperature correction $(z_{ipt})^b$	Hot/cold operation correction $[f(t)]^b$
Carbon monoxide	$-0.0127\,t + 1.95$	$0.0045\,t + 0.02$
Hydrocarbons	$-0.0113\,t + 1.81$	$0.0079\,t + 0.03$
Nitrogen oxides	$-0.0046\,t + 1.36$	$-0.0068\,t + 1.64$

[a] Reference 9. Temperature (t) is expressed in °F. In order to apply these equations, °C must be first converted to °F. The appropriate conversion formula is: $F = (9/5)C + 32$. For temperatures expressed on the Kelvin (K) scale: $F = 9/5\,(K - 273.16) + 32$.

[b] The formulae for z_{ipt} enable the correction of the FTP emission factors for ambient temperature effects only. The amount of cold/hot operation is not affected. The formulae for f(t), on the other hand, are part of equation 3.1.4-2 for calculating r_{iptw}. The variable r_{iptw} corrects for cold/hot operation as well as ambient temperature. Note: z_{ipt} can be applied without r_{iptw}, but not vice versa.

FTP Emission Factor (c_{ipn}). The results of the EPA light-duty truck surveillance programs are summarized in Table 3.1.4-1. These data are divided by geographic area into: low altitude (non-California), high altitude, and California only. California emission factors are presented separately (as a footnote) because light-duty trucks operated in California have been, in the case of several model years, subject to emission standards that differ from those standards applicable to light trucks under the Federal emission control program. Emissions at high altitude are differentiated from those at low altitude to account for the effect that altitude has on air-fuel ratios and concomitant emissions. The tabulated values are applicable to calendar year 1972 for each model year.

Fraction of Annual Travel by Model Year (m_{in}). A sample calculation of this variable is presented in Table 3.1.4-4. In the example, nationwide statistics are used and the fraction of in-use vehicles by model year (vehicle age) are weighted on the basis of the annual miles driven (again, nationwide data are used). The calculation may be "localized" to reflect local (county, state, etc.) vehicle age mix, annual miles driven, or both. Otherwise, the national data can be used. The data presented in Table 3.1.4-3 are for calendar year 1972 only; for later calendar years, see Appendix D.

Speed Correction Factors (v_{ips}). Speed correction factors enable the "adjustment" of FTP emission factors to account for differences in average route speed. Because the implicit average route speed of the FTP is 19.6 mi/hr (31.6 km/hr), estimates of emissions at higher or lower average speeds require a correction.

It is important to note the difference between "average route speed" and "steady speed." Average route speed is trip-related and based on a composite of the driving modes (idle, cruise, acceleration, deceleration) encountered during a typical home-to-work trip, for example. Steady speed is highway-facility-oriented. For instance, a group of vehicles traveling over an uncongested freeway link (with a volume to capacity ratio of 0.1, for example) might be traveling at a steady speed of about 55 mi/hr (89 km/hr). Note, however, that steady speeds, even at the link level, are unlikely to occur where resistance to traffic flow occurs (unsynchronized traffic signaling, congested flow, etc.).

In previous revisions to this section, the limited data available for correcting for average speed were presented graphically. Recent research however, resulted in revised speed relationships by model year.[5] To facilitate the presentation, the data are given as equations and appropriate coefficients in Table 3.1.4-2. These relationships were developed by performing five major tasks. First, urban driving pattern data collected during the CAPE-10 Vehicle Operation Survey[10] were processed by city and time of day into freeway, non-freeway, and composite speed-mode matrices. Second, a large number of driving patterns were computer-generated for a range of average speeds (15 to 45 mi/hr; 24 to 72 km/hr) using weighted combinations of freeway and non-freeway matrices. Each of these patterns was filtered for "representativeness." Third, the 88 resulting patterns were input (second by second speeds) to the EPA modal emission analysis model (see 3.1.2.3).[11] The output of the model was estimated emissions for each of 11 vehicle groups (see Table 3.1.4-2 for a listing of these groups). Fourth, a regression analysis was performed to relate estimated emissions to average route speed for each of the 11 vehicle groups. Fifth, these relationships were normalized to 19.6 mi/hr (31.6 km/hr) and summarized in Table 3.1.4-2.

The equations in Table 3.1.4-2 apply only for the range of the data – from 15 to 45 mi/hr (24 to 72 km/hr). Because of the need, in some situations, to estimate emissions at very low average speeds, correction factors have been developed for this purpose. The speed correction factors for 5 and 10 mi/hr (8 and 16 km/hr) presented in Table 3.1.4-3 were developed using a method somewhat like that described above, again using the modal emission model. Because the modal emission model predicts warmed-up vehicle emissions, the use of this model to develop speed correction factors makes the assumption that a given speed correction factor applies equally well to hot and cold vehicle operation.

Temperature Correction Factor (z_{ipt}). The 1975 FTP requires that emission measurements be made within the limits of a relatively narrow temperature band (68 to 86°F). Such a band facilitates uniform testing in laboratories without requiring extreme ranges of temperature control. Present emission factors for motor vehicle are based on data from the standard Federal test (assumed to be at 75°F). Recently, EPA and the Bureau of Mines undertook a test program to evaluate the effect of ambient temperatures on motor vehicle exhaust emissions levels.[9] The study indicates that changes in ambient temperature result in significant changes in emissions during cold start-up operation. Because many Air Quality Control Regions have temperature characteristics differing considerably from the 68 to 86°F range, the temperature correction factor should be applied. The corrections factors are expressed in equational form and presented in Table 3.1.4-5 and can be applied between 20 and 80°F. For temperatures outside this range, the appropriate endpoint correction factor should be applied.

Hot/Cold Vehicle Operation Correction Factor (r_{iptw}). The 1975 FTP measures emissions over three types of driving: a cold transient phase (representative of vehicle start-up after a long engine-off period), a hot transient phase (representative of vehicle start-up after a short engine-off period), and a stabilized phase (representative of warmed-up vehicle operation). The weighting factors used in the 1975 FTP are 20 percent, 27 percent, and 53 percent of total miles (time) in each of the three phases, respectively. Thus, when the 1975 FTP emission factors are applied to a given region for the purpose of assessing air quality, 20 percent of the light-duty trucks in the area of interest are assumed to be operating in a cold condition, 27 percent in a hot start-up condition, and 53 percent in a hot stabilized condition. For non-catalyst equipped vehicles (all pre-1975 model year vehicles), emission in the two hot phases are essentially equivalent on a grams per mile (g/km) basis. Therefore, the 1975 FTP emission factor represents 20 percent cold operation and 80 percent hot operation.

Many situations exist in which the application of these particular weighting factors may be inappropriate. For example, light-duty truck operation in center city areas may have a much higher percentage of cold operation during the afternoon pollutant emissions peak when work-to-home trips are at a maximum and vehicles have been standing for 8 hours. The hot/cold vehicle operation correction factor allows the cold operation phase to range from 0 to 100 percent of total light-duty truck operations. This correction factor is a function of the percentage of cold operation (w) and the ambient temperature (t). The correction factor is:

$$r_{iptw} = \frac{w+(100-w)f(t)}{20+80f(t)} \qquad (3.1.4\text{-}2)$$

where: f(t) is given in Table 3.1.4-5.

3.1.4.2.2 Crankcase and evaporative hydrocarbon emissions – Evaporative and crankcase hydrocarbon emissions are determined using:

$$f_n = \sum_{i=n-12}^{n} h_i \, m_{in} \qquad (3.1.4\text{-}3)$$

where: f_n = The combined evaporative and crankcase hydrocarbon emission factor for calendar year (n)

h_i = The combined evaporative and crankcase hydrocarbon emission rate for the i^{th} model year. Emission factors for this source are reported in Table 3.1.4-6. The crankcase and evaporative emissions reported in the table are added together to arrive at this variable.

m_{in} = The weighted annual travel of the i^{th} model year vehicle during calendar year (n)

Table 3.1.4-6. CRANKCASE AND EVAPORATIVE HYDROCARBON EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED TRUCKS
EMISSION FACTOR RATING: B

Location	Model years	Crankcase emissions[a]		Evaporative emissions[b]	
		g/mi	g/km	g/mi	g/km
All areas except high altitude and California[c]	Pre-1963	4.6	2.9	3.6	2.2
	1963-1967	2.4	1.5	3.6	2.2
	1968-1970	0.0	0.0	3.6	2.2
	1971	0.0	0.0	3.1	1.9
	1972	0.0	0.0	3.1	1.9
High altitude	Pre-1963	4.6	2.9	4.6	2.9
	1963-1967	2.4	1.5	4.6	2.9
	1968-1970	0.0	0.0	4.6	2.9
	1971-1972	0.0	0.0	3.9	2.4

[a] Reference 12. Tabulated values were determined by assuming that two-thirds of the light-duty trucks are 6000 lbs GVW (2700 kg) and under and that one-third are 6001 to 8500 lbs GVW (2700 to 3860 kg).

[b] Light-duty vehicle evaporative data (section 3.1.2) and heavy-duty vehicle evaporative data (Table 3.1.4-8) were used to estimate the values.

[c] For California: Evaporative emissions for the 1970 model year are 1.9 g/km (3.1 g/mi). All other model years are the same as those reported as "All areas except high altitude and California." Crankcase emissions for the pre-1961 California light-duty trucks are 4.6 g/mi (2.9 g/km) and 1961-1963 models years are 2.4 g/mi (1.5 g/km) all post-1963 model year vehicles are 0.0 g/mi (0.0 g/km).

3.1.4.2.3 Sulfur oxide and particulate emissions – Sulfur oxide and particulate emission factors for all model year light trucks are presented in Table 3.1.4-7. Sulfur oxides factors are based on fuel sulfur content and fuel consumption. Tire-wear particulate factors are based on automobile test results, a premise necessary because of the lack of data. Light truck tire wear is likely to result in greater particulate emissions than automobiles because of larger tires and heavier loads on tires.

Table 3.1.4-7. PARTICULATE AND SULFUR OXIDES EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED TRUCKS
EMISSION FACTOR RATING: C

Pollutant	Emissions, Pre-1973 vehicles	
	g/mi	g/km
Particulate[a]		
Exhaust	0.34	0.21
Tire wear[b]	0.20	0.12
Sulfur oxides[c] (SO_x as SO_2)	0.18	0.11

[a] References 13 and 14. Based on tests of automobiles.

[b] Reference 14 summarized tests of automotive tire wear particulate. It is assumed that light-duty truck emissions are similar. The automotive tests assume a four-tire vehicle. If corrections for vehicles with a greater number of tires are needed, multiply the above value by the number of tires and divide by four.

[c] Based on an average fuel consumption 10.0 mi/gal (4.3 km/liter) from Reference 15 and on the use of a fuel with a 0.032 percent sulfur content from References 17 and 18 and a density of 6.1 lb/gal (0.73 kg/liter) from References 17 and 18.

3.1.4.3 Heavy-Duty Vehicle Emissions – Emissions research on heavy-duty, gasoline-powered vehicles has been limited in contrast to that for light-duty vehicles and light-duty trucks. As a result, cold operation correction factors, temperature correction factors, speed correction factors, idle emission rates, etc. are not available for heavy-duty vehicles. For some of these variables, however, light-duty vehicle data can be applied to heavy-duty vehicles. In instances in which light-duty vehicle data are not appropriate, a value of unity if assumed.

3.1.4.3.1 Carbon monoxide, hydrocarbon, and nitrogen oxides emissions – The calculation of heavy-duty, gasoline-powered vehicle exhaust emission factors can be accomplished using:

$$e_{nps} = \sum_{i=n-12}^{n} c_{ipn} \, m_{in} \, v_{ips} \qquad (3.1.4\text{-}4)$$

where: e_{nps} = Composite emission factor in grams per mile (grams per kilometer) for calendar year (n) and pollutant (p) and average speed(s)

c_{ipn} = The test procedure emission rate (Table 3.1.4-8) for pollutant (p) in g/mi (g/km) for the i^{th} model year in calendar year (n)

m_{in} = The weighted annual travel of the i^{th} model year vehicles during calendar year (n). The determination of this variable involves the use of the vehicle year distribution.

v_{ips} = The speed correction factor for the i^{th} model year vehicles for pollutant (p) and average speed(s)

Table 3.1.4-8. EXHAUST EMISSION FACTORS FOR HEAVY-DUTY, GASOLINE-POWERED TRUCKS FOR CALENDAR YEAR 1972[a]

EMISSION FACTOR RATING: B

Location	Model year	Carbon monoxide g/mi	Carbon monoxide g/km	Exhaust hydrocarbons g/mi	Exhaust hydrocarbons g/km	Nitrogen oxides g/mi	Nitrogen oxides g/km
All areas except high altitude	Pre-1970	238	148	35.4	22.0	6.8	4.2
	1970	188	117	13.8	8.6	12.6	7.8
	1971	188	117	13.7	8.5	12.6	7.8
	1972	188	117	13.6	8.4	12.5	7.8
High altitude only[b]	Pre-1970	359	223	48.6	30.2	4.1	2.5
	1970	299	186	15.0	9.3	8.1	5.0
	1971	299	186	14.9	9.3	8.1	5.0
	1972	299	186	14.8	9.2	8.1	5.0

[a] Data from References 19 and 20.

[b] Based on light-duty emissions at high altitude compared with light-duty emissions at low altitudes.

A brief discussion of the variables presented in the above equation is necessary to help clarify their formulation and use. The following paragraphs further describe the variables c_{ipn}, m_{in}, and v_{ips} as they apply to heavy-duty, gasoline-powered vehicles.

Test procedure emission factor (c_{ipn}). The emission factors for heavy-duty vehicles (Table 3.1.4-8) for all areas are based on tests of vehicles operated on-the-road over the San Antonio Road Route (SARR). The SARR, located in San Antonio, Texas, is 7.24 miles long and includes freeway, arterial, and local/collector highway segments.[19] A constant volume sampler is carried on board each of the test vehicles for collection of a proportional part of the exhaust gas from the vehicle. This sample is later analyzed to yield mass emission rates. Because the SARR is an actual road route, the average speed varies depending on traffic conditions at the time of the test. The average speed tends to be around 18 mi/hr (29 km/hr) with about 20 percent of the time spent at idle. The test procedure emission factor is composed entirely of warmed-up vehicle operation. Based on preliminary analysis of vehicle operation data[6], almost all heavy-duty vehicle operation is under warmed-up conditions.

Weighted annual mileage (m_{in}). The determination of this variable is illustrated in Table 3.1.4-9. For purposes of this illustration, nation-wide statistics have been used. Localized data, if available, should be substituted when calculating the variable m_{in} for a specific area under study.

Table 3.1.4-9. SAMPLE CALCULATION OF FRACTION OF GASOLINE-POWERED, HEAVY-DUTY VEHICLE ANNUAL TRAVEL BY MODEL YEAR[a]

Age, years	Fraction of total vehicles in use nationwide (a)[b]	Average annual miles driven (b)	a x b	Fraction of annual travel (m)[c]
1	0.037	19,000	703	0.062
2	0.070	18,000	1,260	0.111
3	0.078	17,000	1,326	0.117
4	0.086	16,000	1,376	0.122
5	0.075	14,000	1,050	0.093
6	0.075	12,000	900	0.080
7	0.075	10,000	750	0.066
8	0.068	9,500	646	0.057
9	0.059	9,000	531	0.047
10	0.053	8,500	451	0.040
11	0.044	8,000	352	0.031
12	0.032	7,500	240	0.021
≥ 13	0.247	7,000	1,729	0.153

[a] Vehicles in use by model year as of 1972 (Reference 7).
[b] Reference 7.
[c] $m = ab/\Sigma ab$.

Speed correction factor (v_{ips}). Data based on tests of heavy-duty emissions versus average speed are unavailable. In the absence of these data, light-duty vehicle speed correction factors are recommended. The data presented in Tables 3.1.4-10 and Table 3.1.4-11 should be considered as interim heavy-duty vehicle speed correction factors until appropriate data become available.

Table 3.1.4-10. SPEED CORRECTION FACTORS FOR HEAVY-DUTY VEHICLES[a,b]

Location	Model year	$v_{ips} = e^{(A + BS + CS^2)}$						$v_{ips} = A + BS$	
		Hydrocarbons			Carbon monoxide			Nitrogen oxides	
		A	B	C	A	B	C	A	B
Low altitude	Pre-1970	0.953	-6.00×10^{-2}	5.81×10^{-4}	0.967	-6.07×10^{-2}	5.78×10^{-4}	0.808	0.980×10^{-2}
	1970-1972	1.070	-6.63×10^{-2}	5.98×10^{-4}	1.047	-6.52×10^{-2}	6.01×10^{-4}	0.888	0.569×10^{-2}
High altitude	Pre-1970	0.883	-5.58×10^{-2}	5.52×10^{-4}	0.721	-4.57×10^{-2}	4.56×10^{-4}	0.602	2.027×10^{-2}
	1970-1972	0.722	-4.63×10^{-2}	4.80×10^{-4}	0.662	-4.23×10^{-2}	4.33×10^{-4}	0.642	1.835×10^{-2}

[a] Reference 5. Equations should not be extended beyond the range of data (15 to 45 mi/hr). These data are from tests of light-duty vehicles and are assumed applicable to heavy-duty vehicles.

[b] Speed (s) is in miles per hour (1 mi/hr = 1.61 km/hr).

101<

Table 3.1.4-11. LOW AVERAGE SPEED CORRECTION FACTORS FOR HEAVY-DUTY VEHICLES[a]

Location	Model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
		5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)	5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)	5 mi/hr (8 km/hr)	10 mi/hr) (16 km/hr)
Low altitude	Pre-1970	2.72	1.57	2.50	1.45	1.08	1.03
	1970-1972	3.06	1.75	2.96	1.66	1.04	1.00
High altitude	Pre-1970	2.29	1.48	2.34	1.37	1.33	1.20
	1970-1972	2.43	1.54	2.10	1.27	1.22	1.18

[a] Driving patterns developed from CAPE-21 vehicle operation data (Reference 6) were input to the modal emission analysis model (see section 3.1.2.3). The results predicted by the model (emissions at 5 and 10 mi/hr; 8 and 16 km/hr) were divided by FTP emission factors for hot operation to obtain the above results. The above data represent the best currently available information for light-duty vehicles. These data are assumed applicable to heavy-duty vehicles given the lack of better information.

For an explanation of the derivation of these factors, see section 3.1.4.2.1.

In addition to exhaust emission factors, the calculation of evaporative and crankcase hydrocarbon emissions are determined using:

$$f_n = \sum_{i=n-12}^{n} h_i m_{in} \qquad (3.1.4\text{-}5)$$

where: f_n = The combined evaporative and crankcase hydrocarbon emission factor for calendar year (n)

h_i = The combined evaporative and crankcase hydrocarbon emission rate for the i^th^ model year. Emission factors for this source are reported in Table 3.1.4-12.

m_{in} = The weighted annual travel of the i^{th} model year vehicle during calendar year (n)

Table 3.1.4-12. CRANKCASE AND EVAPORATIVE HYDROCARBON EMISSION FACTORS FOR HEAVY-DUTY, GASOLINE-POWERED VEHICLES
EMISSION FACTOR RATING: B

Location	Model years	Crankcase hydrocarbon[a]		Evaporative hydrocarbons[b]	
		g/mi	g/km	g/mi	g/km
All areas except high altitude and California	Pre-1968	5.7	3.5	5.8	3.6
	1968-1972	0.0	0.0	5.8	3.6
California only	Pre-1964	5.7	3.5	5.8	3.6
	1964-1972	0.0	0.0	5.8	3.6
High altitude	Pre-1968	5.7	3.5	7.4	4.6
	1968-1972	0.0	0.0	7.4	4.6

[a] Crankcase factors are from Reference 12.

[b] References 1, 21, and 22 were used to estimate evaporative emission factors for heavy-duty vehicles. Equation 3.1.2-6 was used to calculate g/mi (g/km) values. (Evaporative emission factor = g + kd). The heavy-duty vehicle diurnal evaporative emissions (g) were assumed to be three times the light-duty vehicle value to account for the larger size fuel tanks used on heavy-duty vehicles. Nine trips per day (d = number of trips per day) from Reference 6 were used in conjunction with the light-duty vehicle hot soak emissions (k) to yield a total evaporative emission rate in grams per day. This value was divided by 36.2 mi/day (58.3 km/day) from Reference 7 to obtain the per mile (per kilometer) rate.

3.1.4.3.2 Sulfur oxide and particulate emissions – Sulfur oxide and particulate emission factors for all model year heavy-duty vehicles are presented in Table 3.1.4-13. Sulfur oxides factors are based on fuel sulfur content and fuel consumption. Tire-wear particulate factors are based on automobile test results – a premise necessary because of the lack of data. Truck tire wear is likely to result in greater particulate emissions than automobiles because of larger tires, heavier loads on tires, and more tires per vehicle. Although the factors presented in Table 3.1.4-13 can be adjusted for the number of tires per vehicle, adjustments cannot be made to account for the other differences.

Table 3.1.4-13. PARTICULATE AND SULFUR OXIDES EMISSION FACTORS FOR HEAVY-DUTY, GASOLINE-POWERED VEHICLES
EMISSION FACTOR RATING: B

Pollutant	Emissions	
	g/mi	g/km
Particulate		
Exhaust[a]	0.91	0.56
Tire wear[b]	0.20T	0.12T
Sulfur oxides[c] (SO_x as SO_2)	0.36	0.22

[a] Calculated from the Reference 13 value of 12 lb/10^3 gal (1.46 g/liter) gasoline. A 6.0 mi/gal (2.6 km/liter) value from Reference 23 was used to convert to a per kilometer (per mile) emission factor.

[b] Reference 14. The data from this reference are for passenger cars. In the absence of specific data for heavy-duty vehicles, they are assumed to be representative of truck-tire-wear particulate. An adjustment is made for trucks with more than four tires. T equals the number of tires divided by four.

[c] Based on an average fuel consumption of 6.0 mi/gal (2.6 km/liter) from Reference 23, on a 0.04 percent sulfur content from Reference 16 and 17, and on a density of 6.1 lb/gal (0.73 kg/liter) from References 16 and 17.

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3.1.5 Heavy-Duty, Diesel-Powered Vehicles

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3.1.5.1 General[1,2] – On the highway, heavy-duty diesel engines are primarily used in trucks and buses. Diesel engines in any application demonstrate operating principles that are significantly different from those of the gasoline engine.

3.1.5.2 Emissions – Diesel trucks and buses emit pollutants from the same sources as gasoline-powered vehicles: exhaust, crankcase blow-by, and fuel evaporation. Blow-by is practically eliminated in the diesel, however, because only air is in the cylinder during the compression stroke. The low volatility of diesel fuel along with the use of closed injection systems essentially eliminates evaporation losses in diesel systems.

Exhaust emissions from diesel engines have the same general characteristics of auto exhausts. Concentrations of some of the pollutants, however, may vary considerably. Emissions of sulfur dioxide are a direct function of the fuel composition. Thus, because of the higher average sulfur content of diesel fuel (0.20 percent S) as compared with gasoline (0.035 percent S), sulfur dioxide emissions are relatively higher from diesel exhausts.[3,4]

Because diesel engines allow more complete combustion and use less volatile fuels than spark-ignited engines, their hydrocarbon and carbon monoxide emissions are relatively low. Because hydrocarbons in diesel exhaust represent largely unburned diesel fuel, their emissions are related to the volume of fuel sprayed into the combustion chamber. Both the high temperature and the large excesses of oxygen involved in diesel combustion are conducive to high nitrogen oxide emission, however.[6]

Particulates from diesel exhaust are in two major forms – black smoke and white smoke. White smoke is emitted when the fuel droplets are kept cool in an environment abundant in oxygen (cold starts). Black smoke is emitted when the fuel droplets are subjected to high temperatures in an environment lacking in oxygen (road conditions).

Emissions from heavy-duty diesel vehicles during a calendar year (n) and for a pollutant (p) can be approximately calculated using:

$$e_{nps} = \sum_{i=n-12}^{n} c_{ipn} v_{ips} \qquad (3.1.5\text{-}1)$$

where: e_{nps} = Composite emission factor in g/mi (g/km) for calendar year (n), pollutant (p), and average speed (s)

c_{ipn} = The emission rate in g/mi (g/km) for the i^{th} model year vehicles in calendar year (n) over a transient urban driving schedule with an average speed of approximately 18 mi/hr (29 km/hr)

v_{ips} = The speed correction factor for the i^{th} model year heavy-duty diesel vehicles for pollutant (p) and average speed (s)

Values for c_{ipn} are given in Table 3.1.5-1. These emission factors are based on tests of vehicles on-the-road over the San Antonio Road Route (SARR). The SARR, located in San Antonio, Texas, is 7.24 miles long and includes freeway, arterial, and local/collector highway segments.[7] A constant volume sampler is carried on board each test vehicle for collection of a proportional part of the vehicle's exhaust. This sample is later analyzed to yield mass emission rates. Because the SARR is an actual road route, the average speed varies depending on traffic conditions at the time of the test. The average speed, however, tends to be around 18 mi/hr (29 km/hr), with about 20 percent of the time spent at idle. The test procedure emission factor is composed entirely of warmed-up vehicle operation. Based on a preliminary analysis of vehicle operation data, heavy-duty vehicles operate primarily (about 95 percent) in a warmed-up condition.

Table 3.1.5-1. EMISSION FACTORS FOR HEAVY-DUTY, DIESEL-POWERED VEHICLES (ALL PRE-1973 MODEL YEARS) FOR CALENDAR YEAR 1972
EMISSION FACTOR RATING: B

Pollutant	Truck emissions[a]		City bus emissions[b]	
	g/mi	g/km	g/mi	g/km
Particulate[c]	1.3	0.81	1.3	0.81
Sulfur oxides[c,d] (SO_x as SO_2)	2.8	1.7	2.8	1.7
Carbon monoxide	28.7	17.8	21.3	13.2
Hydrocarbons	4.6	2.9	4.0	2.5
Nitrogen oxides (NO_x as NO_2)	20.9	13.0	21.5	13.4
Aldehydes[c] (as HCHO)	0.3	0.2	0.3	0.2
Organic acids[c]	0.3	0.2	0.3	0.2

[a] Truck emissions are based on over-the-road sampling of diesel trucks by Reference 7. Sampling took place on the San Antonio (Texas) Road Route (SARR), which is 7.24 miles (11.7 kilometers) long and includes freeway, arterial, and local/collector highway segments. Vehicles average about 18 mi/hr (29 km/hr) over this road route.

[b] Bus emission factors are also based on the SARR. 13-Mode emission data from Reference 6 were converted to SARR values using cycle-to-cycle conversion factors from Reference 8.

[c] Reference 6. Tire wear particulate not included in above particulate emission factors. See tire wear particulate, heavy-duty gasoline section.

[d] Data based on assumed fuel sulfur content of 0.20 percent. A fuel economy of 4.6 mi/gal (2.0 km/liter) was used from Reference 9.

The speed correction factor, v_{ips}, can be computed using data in Table 3.1.5-2. Table 3.1.5-2 gives heavy-duty diesel HC, CO, and NO_x emission factors in grams per minute for the idle mode, an urban transient mode with average speed of 18 mi/hr (29 km/hr), and an over-the-road mode with an average speed of approximately 60 mi/hr (97 km/hr). For average speeds less than 18 mi/hr (29 km/hr), the correction factor is:

$$v_{ips} = \frac{\text{Urban} + \left(\frac{18}{S} - 1\right)\text{ Idle}}{\text{Urban}} \tag{3.1.5-2}$$

where: s is the average speed of interest (in mi/hr), and the urban and idle values (in g/min) are obtained from Table 3.1.5-2. For average speeds above 18 mi/hr (29 km/hr), the correction factor is:

$$v_{ips} = \frac{\frac{18}{42S}\left[(60\text{-}S)\text{ Urban} + (S\text{-}18)\text{ Over the Road}\right]}{\text{Urban}} \tag{3.1.5-3}$$

Where: S is the average speed (in mi/hr) of interest. Urban and over-the-road values (in g/min) are obtained from Table 3.1.5-2. Emission factors for heavy-duty diesel vehicles assume all operation to be under warmed-up vehicle conditions. Temperature correction factors, therefore, are not included because ambient temperature has minimal effects on warmed-up operation.

Table 3.1.5-2. EMISSION FACTORS FOR HEAVY-DUTY DIESEL VEHICLES UNDER DIFFERENT OPERATING CONDITIONS
EMISSION FACTOR RATING: B

Pollutant	Emission factors,[a] g/min		
	Idle	Urban [18 mi/hr (29 km/hr)]	Over-the-road [60 mi/hr (97 km/hr]
Carbon monoxide	0.64	8.61	5.40
Hydrocarbons	0.32	1.38	2.25
Nitrogen oxides (NO_x as NO_2)	1.03	6.27	28.3

[a] Reference 7. Computed from data contained in the reference.

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3.1.6 Gaseous-Fueled Vehicles

by David S. Kircher

3.1.6.1 General – Conversion of vehicles to gaseous fuels has been practiced for many years. In the past the principal motivation for the conversion has been the economic advantage of gaseous fuels over gasoline rather than lower air pollutant emission levels that result from their use. Recently, however, conversions have been made for air pollution control as well as for lower operating cost. Liquified petroleum gas (LPG), the most common form of gaseous fuel for vehicles, is currently used to power approximately 300,000 vehicles in the United States. Natural gas, in the form of compressed natural gas (CNG) or liquified natural gas (LNG), is being used nationally to power about 4,000 vehicles.[1] Of the two natural gas fuels, CNG is the most common. Natural gas conversions are usually dual fuel systems that permit operation on either gaseous fuel (CNG or LNG) or gasoline.

3.1.6.2 Emissions – Tables 3.1.6-1 and 3.1.6-2 contain emission factors for light- and heavy-duty vehicles converted for either gaseous fuel or dual fuel operation. The test data used to determine the average light duty emission factors were based on both the 1972 Federal test procedure and the earlier seven-mode method.[7,8] These test data were converted to the current Federal test procedure[9] using conversion factors determined empirically.[10,11] This conversion was necessary to make the emission factors for these vehicles consistent with emission factors reported in previous sections of this chapter.

Heavy-duty vehicle emission factors (Table 3.1.6-2) are based on tests of vehicles on an experimental dynamometer test cycle[6] and on the Federal test procedure. Emissions data for heavy-duty vehicles are limited to tests of only a few vehicles. For this reason the factors listed in table 3.1.6-2 are only approximate indicators of emissions from these vehicles.

Emission data on gaseous-powered vehicles are limited to dynamometer test results. Deterioration factors and speed correction factors are not available. The data contained in the tables, therefore, are emission factors for in-use vehicles at various mileages rather than emission rates (as defined in section 3.1.2).

Emission factors for a particular population of gaseous-fueled vehicles can be determined using the relationship:

$$e_{npwc} = \sum_{i=n-12}^{n+1} c_i f_i \qquad (1)$$

where: e_{npwc} = Emission factor is grams per mile (or g/km) for calendar year (n), pollutant (p), vehicle weight (w) (light- or heavy-duty), and conversion fuel system (c) (e.g. LPG)

c_i = The test cycle emission factor (Tables 3.1.6-1 and 3.1.6-2) for pollutant (p) for the i^{th} model year vehicles

f_i = The fraction of total miles driven by a population of gaseous-fueled vehicles that are driven by the i^{th} model year vehicles

Carbon monoxide, hydrocarbon, and nitrogen oxides emission factors are listed in the tables. Particulates and sulfur oxides are not listed because of the lack of test data. Because stationary external combustion of gaseous fuel results in extremely low particulate and sulfur oxides, it is reasonable to assume that the emissions of these pollutants from gaseous-fueled vehicles are negligible.

Table 3.1.6-1. EMISSION FACTORS BY MODEL YEAR FOR LIGHT-DUTY VEHICLES USING LPG, LPG/DUAL FUEL, OR CNG/DUAL FUEL[a]

EMISSION FACTOR RATING: B

Fuel and model year	Carbon monoxide		Exhaust hydrocarbons		Nitrogen oxides (NO_x as NO_2)	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
LPG						
Pre-1970[b]	11	6.8	1.8	1.1	3.2	2.0
1970 through 1972[c]	3.4	2.1	0.67	0.42	2.8	1.7
LPG/Dual fuel[d]						
Pre-1973	7.8	4.8	2.4	1.5	3.4	2.1
CNG/Dual fuel[e]						
Pre-1973	9.2	5.7	1.5	0.93	2.8	1.7

[a] References 1 through 5.

[b] Emission factors are based on tests of 1968 and 1969 model year vehicles. Sufficient data for earlier models are not available.

[c] Based on tests of 1970 model year vehicles. No attempt was made to predict the emissions resulting from the conversion of post 1974 model year vehicles to gaseous fuels. It is likely that 1973 and 1974 model year vehicles converted to gaseous fuels will emit pollutant quantities similar to those emitted by 1972 vehicles with the possible exception of nitrogen oxides.

[d] The dual fuel system represents certain compromises in emission performance to allow the flexibility of operation on gaseous or liquid (gasoline) fuels. For this reason their emission factors are listed separately from vehicles using LPG only.

[e] Based on tests of 1968 and 1969 model year vehicles. It is likely that 1973 and 1974 model year vehicles will emit similar pollutant quantities to those listed with the possible exception of nitrogen oxides. No attempt was made to estimate 1975 and later model year gaseous-fueled-vehicle emissions.

Table 3.1.6-2. EMISSION FACTORS FOR HEAVY-DUTY VEHICLES USING LPG OR CNG/DUAL FUEL

EMISSION FACTOR RATING: C

Pollutant	Emissions (all model years)[a]			
	LPG[b,c]		CNG/dual fuel[d]	
	g/mi	g/km	g/mi	g/km
Carbon monoxide	4.2	2.6	7.5	4.6
Exhaust hydrocarbons	2.4	1.5	2.2	1.4
Nitrogen oxides (NO_x as NO_2)	2.8	1.7	5.8	3.6

[a] Test results are for 1959 through 1970 model years. These results are assumed to apply to all future heavy-duty vehicles based on present and future emission standards.

[b] References 2 and 4.

[c] LPG values for heavy-duty vehicles are based on a limited number of tests of vehicles tuned for low emissions. Vehicles converted to LPG solely for economic reasons gave much higher emission values. For example, eleven vehicles (1950 through 1963) tested in Reference 6 demonstrated average emissions of 160 g/mi (99 g/km) of carbon monoxide, 8.5 g/mi (5.3 g/km) of hydrocarbons, and 4.2 g/mil (2.6 g/km) of nitrogen oxides.

[d] Reference 5.

References for Section 3.1.6

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3.1.7 Motorcycles

by David S. Kircher

3.1.7.1 General – Motorcycles, which are not, generally, considered an important source of air pollution, have become more popular and their numbers have been steadily increasing in the last few years. Sales grew at an annual rate of 20 percent from 1965 to 1971.[1] The majority of motorcycles are powered by either 2- or 4-stroke, air-cooled engines; however, water-cooled motorcycles and Wankel-powered motorcycles have recently been introduced. Until recently the predominant use of 4-stroke motorcycles was on-highway and the 2-stroke variety was off-highway. This difference in roles was primarily a reflection of significant weight and power variations between available 2- and 4-stroke vehicles. As light-weight 4-strokes and more powerful 2-strokes become available the relative number of motorcycles in each engine category may change. Currently the nationwide population of motorcycles is approximately 38 percent 2-stroke and 62 percent 4-stroke. Individual motorcycles travel, on the average, approximately 4000 miles per year.[1] These figures, along with registration statistics, enable the rough estimation of motorcycle miles by engine category and the computation of resulting emissions.

3.1.7.2 Emissions – The quantity of motorcycle emission data is rather limited in comparison with the data available on other highway vehicles. For instance, data on motorcycle average speed versus emission levels are not available. Average emission factors for motorcycles used on highways are reported in Table 3.1.7-1. These data, from several test vehicles, are based on the Federal light-duty vehicle test procedure.[2] The table illustrates differences in 2-stroke and 4-stroke engine emission rates. On a per mile basis, 2-stroke engines emit nearly five times more hydrocarbons than 4-stroke engines. Both engine categories emit somewhat similar quantities of carbon monoxide and both produce low levels of nitrogen oxides.

Table 3.1.7-1. EMISSION FACTORS FOR MOTORCYCLES[a]
EMISSION FACTOR RATING: B

Pollutant	Emissions			
	2-stroke engine		4-stroke engine	
	g/mi	g/km	g/mi	g/km
Carbon monoxide	27	17	33	20
Hydrocarbons				
Exhaust	16	9.9	2.9	1.8
Crankcase[b]	–	–	0.60	0.37
Evaporative[c]	0.36	0.22	0.36	0.22
Nitrogen oxides (NO_x as NO_2)	0.12	0.075	0.24	0.15
Particulates	0.33	0.21	0.046	0.029
Sulfur oxides[d] (SO_2)	0.038	0.024	0.022	0.014
Aldehydes (RCHO as HCHO)	0.11	0.068	0.047	0.029

[a] Reference 1.

[b] Most 2-stroke engines use crankcase induction and produce no crankcase losses.

[c] Evaporative emissions were calculated assuming that carburetor losses were negligible. Diurnal breathing of the fuel tank (a function of fuel vapor pressure, vapor space in the tank, and diurnal temperature variation) was assumed to account for all the evaporative losses associated with motorcycles. The value presented is based on average vapor pressure, vapor space, and temperature variation.

[d] Calculated using a 0.043 percent sulfur content (by weight) for regular fuel used in 2-stroke engines and 0.022 percent sulfur content (by weight) for premium fuel used in 4-stroke engines.

References for Section 3.1.7

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3.2 OFF-HIGHWAY, MOBILE SOURCES

The off-highway category of internal combustion engines embraces a wide range of mobile and semimobile sources. Emission data are reported in this section on the following sources: aircraft; locomotives; vessels (inboard and outboard); and small general utility engines, such as those used in lawnmowers and minibikes. Other sources that fall into this category, but for which emission data are not currently available, include: snowmobiles, all-terrain vehicles, and farm and construction equipment. Data on these sources will be added to this chapter in future revisions.

3.2.1 Aircraft

by Charles C. Masser

3.2.1.1 General – Aircraft engines are of two major categories; reciprocating (piston) and gas turbine.

The basic element in the aircraft piston engine is the combustion chamber, or cylinder, in which mixtures of fuel and air are burned and from which energy is extracted through a piston and crank mechanism that drives a propeller. The majority of aircraft piston engines have two or more cylinders and are generally classified according to their cylinder arrangement – either "opposed" or radial." Opposed engines are installed in most light or utility aircraft; radial engines are used mainly in large transport aircraft.

The gas turbine engine in general consists of a compressor, a combustion chamber, and a turbine. Air entering the forward end of the engine is compressed and then heated by burning fuel in the combustion chamber. The major portion of the energy in the heated air stream is used for aircraft propulsion. Part of the energy is expended in driving the turbine, which in turn drives the compressor. Turbofan and turboshaft engines use energy from the turbine for propulsion; turbojet engines use only the expanding exhaust stream for propulsion.

The aircraft classification system used is listed in Table 3.2.1-1. Both turbine aircraft and piston engine aircraft have been further divided into sub-classes depending on the size of the aircraft and the most commonly used engine for that class. Jumbo jets normally have approximately 40,000 pounds maximum thrust per engine, and medium-range jets have about 14,000 pounds maximum thrust per engine. For piston engines, this division is more pronounced. The large transport piston engines are in the 500 to 3,000 horsepower range, whereas the small piston engines develop less than 500 horsepower.

Table 3.2.1-1. AIRCRAFT CLASSIFICATION

Aircraft class	Representative aircraft	Engines per aircraft	Engine commonly used
Jumbo jet	Boeing 747	4	Pratt & Whitney JT-9D
	Lockheed L-1011	3	
	McDonald Douglas DC-10	3	
Long-range jet	Boeing 707	4	Pratt & Whitney JT-3D
	McDonald Douglas DC-8	4	
Medium-range jet	Boeing 727	3	Pratt & Whitney JT-8D
	Boeing 737	2	
	McDonald Douglas DC-9	2	
Air carrier turboprop	Convair 580	2	Allison 501-D13
	Electra L-188	4	
	Fairchild Hiller FH-227	2	
Business jet	Gates Learjet	2	General Electric CJ610 Pratt & Whitney JT-12A
	Lockheed Jetstar	4	
General aviation turboprop	–	–	Pratt & Whitney PT-6A
General aviation piston	Cessna 210	1	Teledyne-Continental 0-200 Lycoming 0-320
	Piper 32-300	1	
Piston transport	Douglas DC-6	4	Pratt & Whitney R-2800
Helicopter	Sikorsky S-61	2	General Electric CT-58
	Vertol 107	2	
Military transport			Allison T56A7
Military jet			General Electric J-79 Continental J-69
Military piston			Curtiss-Wright R-1820

3.2.1.2 Landing and Takeoff Cycle – A landing-takeoff (LTO) cycle includes all normal operation modes performed by an aircraft between the time it descends through an altitude of 3,500 feet (1,100 meters) on its approach and the time it subsequently reaches the 3,500 foot (1,100 meters) altitude after take. It should be made clear that the term "operation" used by the Federal Aviation Administration to describe either a landing or a takeoff is not the same as the LTO cycle. Two operations are involved in one LTO cycle. The LTO cycle incorporates the ground operations of idle, taxi, landing run, and takeoff run and the flight operations of takeoff and climbout to 3,500 feet (1,100 meters) and approach from 3,500 feet (1,100 meters) to touchdown

Each class of aircraft has its own typical LTO cycle. In order to determine emissions, the LTO cycle is separated into five distinct modes: (1) taxi-idle, (2) takeoff, (3) climbout, (4) approach and landing, and (5) taxi-idle. Each of these modes has its share of time in the LTO cycle. Table 3.2.1-2 shows typical operating time in each mode for the various types of aircraft classes during periods of heavy activity at a large metropolitan airport. Emissions factors for the complete LTO cycle presented in Table 3.2.1-3 were determined using the typical times shown in Table 3.2.1-2.

Table 3.2.1-2. TYPICAL TIME IN MODE FOR LANDING TAKEOFF CYCLE AT A METROPOLITAN AIRPORT[a]

Aircraft	Time in mode, minutes				
	Taxi-idle	Takeoff	Climbout	Approach	Taxi-idle
Jumbo jet	19.00	0.70	2.20	4.00	7.00
Long range jet	19.00	0.70	2.20	4.00	7.00
Medium range jet	19.00	0.70	2.20	4.00	7.00
Air carrier turboprop	19.00	0.50	2.50	4.50	7.00
Business jet	6.50	0.40	0.50	1.60	6.50
General aviation turboprop	19.00	0.50	2.50	4.50	7.00
General aviation piston	12.00	0.30	4.98	6.00	4.00
Piston transport	6.50	0.60	5.00	4.60	6.50
Helicopter	3.50	0	6.50	6.50	3.50
Military transport	19.00	0.50	2.50	4.50	7.00
Military jet	6.50	0.40	0.50	1.60	6.50
Military piston	6.50	0.60	5.00	4.60	6.50

[a] References 1 and 2.

Table 3.2.1-3. EMISSION FACTORS PER AIRCRAFT LANDING-TAKEOFF CYCLE[a,b]
(lb/engine and kg/engine)
EMISSION FACTOR RATING: B

Aircarft	Solid particulates[a]		Sulfur oxides[d]		Carbon monoxide[e]		Hydrocarbons[e]		Nitrogen oxides[d] (NO_x as NO_2)	
	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg
Jumbo jet	1.30	0.59	1.82	0.83	46.8	21.2	12.2	5.5	31.4	14.2
Long range jet	1.21	0.55	1.56	0.71	47.4	21.5	41.2	18.7	7.9	3.6
Medium range jet	0.41	0.19	1.01	0.46	17.0	7.71	4.9	2.2	10.2	4.6
Air carrier turboprop	1.1	0.49	0.40	0.18	6.6	3.0	2.9	1.3	2.5	1.1
Business jet	0.11	0.05	0.37	0.17	15.8	7.17	3.6	1.6	1.6	0.73
General aviation turboprop	0.20	0.09	0.18	0.08	3.1	1.4	1.1	0.5	1.2	0.54
General aviation piston	0.02	0.01	0.014	0.006	12.2	5.5	0.40	0.18	0.047	0.021
Piston transport	0.56	0.25	0.28	0.13	304.0	138.0	40.7	18.5	0.40	0.18
Helicopter	0.25	0.11	0.18	0.08	5.7	2.6	0.52	0.24	0.57	0.26
Military transport	1.1	0.49	0.41	0.19	5.7	2.6	2.7	1.2	2.2	1.0
Military jet	0.31	0.14	0.76	0.35	15.1	6.85	9.93	4.5	3.29	1.49
Military piston[f]	0.28	0.13	0.14	0.04	152.0	69.0	20.4	9.3	0.20	0.09

[a] References 1 through 5.

[b] Emission factors based on typical times in mode shown in Table 3.2.1-2.

[c] References 1 and 5.

[d] Based on 0.05 percent sulfur content fuel.

[e] References 1, 2, and 4.

[f] Engine emissions based on Pratt & Whitney R-2800 engine scaled down two times.

3.2.1.3 Modal Emission Factors – In Table 3.2.1-4 a set of modal emission factors by engine type are given for carbon monoxide, total hydrocarbons, nitrogen oxides, and solid particulates along with the fuel flow rate per engine for each LTO mode. With this data and knowledge of the time-in-mode, it is possible to construct any LTO cycle or mode and calculate a more accurate estimate of emissions for the situation that exists at a specific airport. This capability is especially important for estimating emissions during the taxi-idle mode when large amounts of carbon monoxide and hydrocarbons are emitted. At smaller commercial airports the taxi-idle time will be less than at the larger, more congested airports.

Table 3.2.1-4. MODAL EMISSION FACTORS[a]
EMISSION FACTOR RATING: B

Engine and mode	Fuel rate		Carbon monoxide		Hydrocarbons		Nitrogen oxides (NO_x as NO_2)		Solid particulates	
	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr
Pratt & Whitney JT-9D (Jumbo jet)										
Taxi-idle	1,738	788	102.0	46.3	27.3	12.4	6.06	2.75	2.2	1.0
Takeoff	17,052	7,735	8.29	3.76	2.95	1.34	720.0	327.0	3.75	1.7
Climbout	14,317	6,494	11.7	5.31	2.65	1.20	459.0	208.0	4.0	1.8
Approach	5,204	2,361	32.6	14.8	3.00	1.36	54.1	24.5	2.3	1.0
General Electric CF6 (Jumbo jet)										
Taxi-idle	1,030	467	51.7	23.5	15.4	7.0	3.6	1.63	0.04	0.02
Takeoff	13,449	6,100	6.7	3.04	1.3	0.59	540.0	245.0	0.54	0.24
Climbout[b]	11,400	5,171	6.6	2.99	1.3	0.59	333.0	151.0	0.54	0.24
Approach	6,204	2,814	18.6	8.44	1.9	0.86	173.0	78.5	0.44	0.20
Pratt & Whitney JT-3D (Long range jet)										
Taxi-idle	872	396	109.0	49.4	98.6	44.7	1.43	0.649	0.45	0.20
Takeoff	10,835	4,915	12.3	5.60	4.65	2.11	148.0	67.1	8.25	3.7
Climbout	8,956	4,062	15.3	6.94	4.92	2.23	96.2	43.6	8.5	3.9
Approach	4,138	1,877	39.7	18.0	7.84	3.56	21.8	9.89	8.0	3.6
Pratt & Whitney JT-3C (Long range jet)										
Taxi-idle	1,198	543	92.6	42.0	92.2	41.8	2.49	1.13	0.40	0.18
Takeoff	10,183	4,619	9.04	4.10	0.855	0.388	119.0	54.0	6.50	2.9
Climbout	8,509	3,860	16.0	7.26	0.893	0.405	84.7	38.4	6.25	2.8
Approach	4,115	1,867	49.0	22.2	8.26	3.75	23.2	10.5	3.25	1.5
Pratt & Whitney JT-4A (Long range jet)										
Taxi-idle	1,389	630	62.8	28.5	64.8	29.4	2.71	1.23	1.2	0.54
Takeoff	15,511	7,036	18.8	8.53	0.674	0.306	236.0	107.0	21.0	9.5
Climbout	13,066	5,927	18.3	8.30	1.27	0.576	155.0	70.3	20.0	9.1
Approach	5,994	2,719	26.3	11.9	3.83	1.74	35.9	16.3	6.0	2.7

Table 3.2.1-4 (continued). MODAL EMISSION FACTORS[a]
EMISSION FACTOR RATING: B

Engine and mode	Fuel rate		Carbon monoxide		Hydrocarbons		Nitrogen oxides (NO_x as NO_2)		Solid particulates	
	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	Kg/hr	lb/hr	kg/hr	lb/hr	kg/hr
General Electric CJ805 (Long range jet)										
Taxi-idle	1,001	454	63.8	28.9	27.3	12.4	1.57	0.712	1.3	0.59
Takeoff	9,960	4,518	29.1	13.2	0.556	0.252	111.0	50.3	15.0	6.8
Climbout	8,290	3,760	28.9	13.1	0.583	0.264	74.0	33.6	15.0	6.8
Approach	3,777	1,713	42.8	19.4	2.43	1.10	17.8	8.07	5.0	2.3
Pratt & Whitney JT-8D[c] (Med. range jet)										
Taxi-idle	959	435	33.4	15.2	6.99	3.71	2.91	1.32	0.36	0.16
Takeoff	8,755	3,971	7.49	3.40	0.778	0.353	198.0	89.8	3.7	1.7
Climbout	7,337	3,328	8.89	4.03	0.921	0.418	131.0	59.4	2.6	1.2
Approach	3,409	1,546	18.2	8.26	1.75	0.794	30.9	14.0	1.5	0.68
Rolls Royce Sprey MK511 (Med. range jet)										
Taxi-idle	662	300	60.2	27.3	66.1	30.0	0.849	0.385	0.17	0.077
Takeoff	7,625	3,459	14.2	6.44	Neg	Neg	153.0	69.4	16.0	7.3
Climbout	6,355	2,883	15.3	6.94	0.242	0.110	115.0	52.2	10.0	4.5
Approach	3,052	1,384	39.1	17.7	4.22	1.91	30.4	13.8	1.5	0.68
Allison T56-A15 (Air carrier turboprop; mil. transport)										
Taxi-idle	493	224	8.74	3.96	7.39	3.35	1.23	0.560	1.6	0.73
Takeoff	2,393	1,085	3.77	1.71	0.440	0.200	27.9	12.7	3.7	1.7
Climbout	2,188	992	3.40	1.54	0.399	0.181	22.2	10.1	3.0	1.4
Approach	1,146	520	3.49	1.58	0.326	0.148	7.32	3.32	3.0	1.4
Allison T56-A7 (Air carrier turboprop; mil. transport)										
Taxi-idle	548	249	15.3	6.94	6.47	2.93	2.16	0.980	1.6	0.73
Takeoff	2,079	943	2.15	0.975	0.430	0.195	22.9	10.4	3.7	1.7
Climbout	1,908	865	3.01	1.37	0.476	0.216	21.2	9.62	3.0	1.4
Approach	1,053	478	3.67	1.66	0.517	0.235	7.78	3.53	3.0	1.4

Table 3.2.1-4 (continued). MODAL EMISSION FACTORS[a]
EMISSION FACTOR RATING: B

Engine and mode	Fuel rate		Carbon monoxide		Hydrocarbons		Nitrogen oxides (NO_x as NO_2)		Solid particulates	
	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr
Airesearch TPE-331[d] (Gen. aviation turboprop)										
Taxi-idle	146	66.2	3.53	1.60	0.879	0.399	0.955	0.433	0.3	0.14
Takeoff	365	166.0	0.393	0.178	0.055	0.025	3.64	1.65	0.8	0.36
Climbout	339	154.0	0.568	0.258	0.053	0.024	3.31	1.50	0.6	0.27
Approach	206	93.4	2.58	1.17	0.240	0.109	1.69	0.767	0.6	0.27
Teledyne/Continental 0-200 (Gen. aviation piston)										
Taxi-idle	7.68	3.48	7.52	3.41	0.214	0.097	0.009	0.004	NA[e]	NA
Takeoff	48.4	22.0	54.6	24.8	0.720	0.327	0.259	0.117	NA	NA
Climbout	48.4	22.0	54.6	24.8	0.720	0.327	0.259	0.117	NA	NA
Approach	21.3	9.66	23.8	10.8	0.380	0.172	0.052	0.024	NA	NA
Lycoming 0-320 (Gen. aviation piston)										
Taxi-idle	13.0	5.90	11.1	5.03	0.355	0.161	0.013	0.006	NA	NA
Takeoff	65.7	29.8	70.9	32.2	1.49	0.676	0.214	0.097	NA	NA
Climbout	63.5	28.8	65.8	29.8	1.31	0.594	0.375	0.170	NA	NA
Approach	23.1	10.5	24.3	11.0	0.496	0.225	0.051	0.023	NA	NA

[a] References 4 and 5.
[b] Estimated and/or calculated.
[c] "Diluted smokeless" JT-8D. All air carriers scheduled for conversion of JT-8D engines to smokeless by January 1973.
[d] Similar to the PT-6A engine.
[e] NA–Not available.

References for Section 3.2.1

1. Nature and Control of Aircraft Engine Exhaust Emissions. Northern Research and Engineering Corporation, Cambridge, Mass. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number PH22-68-27. November 1968.

2. The Potential Impact of Aircraft Emissions upon Air Quality. Northern Research and Engineering Corporation, Cambridge, Mass. Prepared for the Environmental Protection Agency, Research Triangle Park, N.C., under Contract Number 68-02-0085. December 1971.

3. Assessment of Aircraft Emission Control Technology. Northern Research and Engineering Corporation, Cambridge, Mass. Prepared for the Environmental Protection Agency, Research Triangle Park, N.C., under Contract Number 68-04-0011. September 1971.

4. Analysis of Aircraft Exhaust Emission Measurements. Cornell Aeronautical Laboratory Inc. Buffalo, N.Y. Prepared for the Environmental Protection Agency, Research Triangle Park, N.C., under Contract Number 68-04-0040. October 1971.

5. Private communication with Dr. E. Karl Bastress. IKOR Incorporated. Burlington, Mass. November 1972.

3.2.2 Locomotives

by David S. Kircher

3.2.2.1 General – Railroad locomotives generally follow one of two use patterns: railyard switching or road-haul service. Locomotives can be classified on the basis of engine configuration and use pattern into five categories: 2-stroke switch locomotive (supercharged), 4-stroke switch locomotive, 2-stroke road service locomotive (supercharged), 2-stroke road service locomotive (turbocharged), and 4-stroke road service locomotive.

The engine duty cycle of locomotives is much simpler than many other applications involving diesel internal combustion engines because locomotives usually have only eight throttle positions in addition to idle and dynamic brake. Emission testing is made easier and the results are probably quite accurate because of the simplicity of the locomotive duty cycle.

3.2.2.2 Emissions – Emissions from railroad locomotives are presented two ways in this section. Table 3.2.2-1 contains average factors based on the nationwide locomotive population breakdown by category. Table 3.2.2-2 gives emission factors by locomotive category on the basis of fuel consumption and on the basis of work output (horsepower hour).

The calculation of emissions using fuel-based emission factors is straightforward. Emissions are simply the product of the fuel usage and the emission factor. In order to apply the work output emission factor, however, an

Table 3.2.2-1. AVERAGE LOCOMOTIVE EMISSION FACTORS BASED ON NATIONWIDE STATISTICS[a]

Pollutant	Average emissions[b]	
	lb/10^3 gal	kg/10^3 liter
Particulates[c]	25	3.0
Sulfur oxides[d] (SO_x as SO_2)	57	6.8
Carbon monoxide	130	16
Hydrocarbons	94	11
Nitrogen oxides (NO_x as NO_2)	370	44
Aldehydes (as HCHO)	5.5	0.66
Organic acids[c]	7	0.84

[a] Reference 1.

[b] Based on emission data contained in Table 3.2.2-2 and the breakdown of locomotive use by engine category in the United States in Reference 1.

[c] Data based on highway diesel data from Reference 2. No actual locomotive particulate test data are available.

[d] Based on a fuel sulfur content of 0.4 percent from Reference 3.

Table 3.2.2-2. EMISSION FACTORS BY LOCOMOTIVE ENGINE CATEGORY[a]
EMISSION FACTOR RATING: B

	Engine category				
Pollutant	2-Stroke supercharged switch	4-Stroke switch	2-Stroke supercharged road	2-Stroke turbocharged road	4-Stroke road
Carbon monoxide					
$lb/10^3$ gal	84	380	66	160	180
$kg/10^3$ liter	10	46	7.9	19	22
g/hphr	3.9	13	1.8	4.0	4.1
g/metric hphr	3.9	13	1.8	4.0	4.1
Hydrocarbon					
$lb/10^3$ gal	190	146	148	28	99
$kg/10^3$ liter	23	17	18	3.4	12
g/hphr	8.9	5.0	4.0	0.70	2.2
g/metric hphr	8.9	5.0	4.0	0.70	2.2
Nitrogen oxides (NO_x as NO_2)					
$lb/10^3$ gal	250	490	350	330	470
$kg/10^3$ liter	30	59	42	40	56
g/hphr	11	17	9.4	8.2	10
g/metric hphr	11	17	9.4	8.2	10

[a] Use average factors (Table 3.2.2-1) for pollutants not listed in this table.

additional calculation is necessary. Horsepower hours can be obtained using the following equation:

$$w = lph$$

where:

w = Work output (horsepower hour)

l = Load factor (average power produced during operation divided by available power)

p = Available horsepower

h = Hours of usage at load factor (l)

After the work output has been determined, emissions are simply the product of the work output and the emission factor. An approximate load factor for a line-haul locomotive (road service) is 0.4; a typical switch engine load factor is approximately 0.06.[1]

References for Section 3.2.2

1. Hare, C.T. and K.J. Springer. Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines. Part 1. Locomotive Diesel Engines and Marine Counterparts. Final Report. Southwest Research Institute. San Antonio, Texas Prepared for the Environmental Protection Agency, Research Triangle Park, N.C., under Contract Number EHA 70-108. October 1972.

2. Young, T.C. Unpublished Data from the Engine Manufacturers Association. Chicago, Ill. May 1970.

3. Hanley, G.P. Exhaust Emission Information on Electro-Motive Railroad Locomotives and Diesel Engines. General Motors Corp. Warren, Mich. October 1971.

3.2.3 Inboard-Powered Vessels

Revised by David S. Kircher

3.2.3.1 General – Vessels classified on the basis of use will generally fall into one of three categories: commercial, pleasure, or military. Although usage and population data on vessels are, as a rule, relatively scarce, information on commercial and military vessels is more readily available than data on pleasure craft. Information on military vessels is available in several study reports,[1-5] but data on pleasure craft are limited to sales-related facts and figures.[6-10]

Commercial vessel population and usage data have been further subdivided by a number of industrial and governmental researchers into waterway classifications[11-16] (for example, Great Lakes vessels, river vessels, and coastal vessels). The vessels operating in each of these waterway classes have similar characteristics such as size, weight, speed, commodities transported, engine design (external or internal combustion), fuel used, and distance traveled. The wide variation between classes, however, necessitates the separate assessment of each of the waterway classes with respect to air pollution.

Information on military vessels is available from both the U.S. Navy and the U.S. Coast Guard as a result of studies completed recently. The U.S. Navy has released several reports that summarize its air pollution assessment work.[3-5] Emission data have been collected in addition to vessel population and usage information. Extensive study of the air pollutant emissions from U.S. Coast Guard watercraft has been completed by the U.S. Department of Transportation. The results of this study are summarized in two reports.[1-2] The first report takes an in-depth look at population/usage of Coast Guard vessels. The second report, dealing with emission test results, forms the basis for the emission factors presented in this section for Coast Guard vessels as well as for non-military diesel vessels.

Although a large portion of the pleasure craft in the U.S. are powered by gasoline outboard motors (see section 3.2.4 of this document), there are numerous larger pleasure craft that use inboard power either with or without "out-drive" (an outboard-like lower unit). Vessels falling into the inboard pleasure craft category utilize either Otto cycle (gasoline) or diesel cycle internal combustion engines. Engine horsepower varies appreciably from the small "auxiliary" engine used in sailboats to the larger diesels used in yachts.

3.2.3.2 Emissions

Commercial vessels. Commercial vessels may emit air pollutants under two major modes of operation: underway and at dockside (auxiliary power).

Emissions underway are influenced by a great variety of factors including power source (steam or diesel), engine size (in kilowatts or horsepower), fuel used (coal, residual oil, or diesel oil), and operating speed and load. Commercial vessels operating within or near the geographic boundaries of the United States fall into one of the three categories of use discussed above (Great Lakes, rivers, coastline). Tables 3.2.3-1 and 3.2.3-2 contain emission information on commercial vessels falling into these three categories. Table 3.2.3-3 presents emission factors for diesel marine engines at various operating modes on the basis of horsepower. These data are applicable to any vessel having a similar size engine, not just to commercial vessels.

Unless a ship receives auxiliary steam from dockside facilities, goes immediately into drydock, or is out of operation after arrival in port, she continues her emissions at dockside. Power must be made available for the ship's lighting, heating, pumps, refrigeration, ventilation, etc. A few steam ships use auxiliary engines (diesel) to supply power, but they generally operate one or more main boilers under reduced draft and lowered fuel rates–a very inefficient process. Motorships (ships powered by internal combustion engines) normally use diesel-powered generators to furnish auxiliary power.[17] Emissions from these diesel-powered generators may also be a source of underway emissions if they are used away from port. Emissions from auxiliary power systems, in terms of the

Table 3.2.3-1. AVERAGE EMISSION FACTORS FOR COMMERCIAL MOTORSHIPS BY WATERWAY CLASSIFICATION
EMISSION FACTOR RATING: C

Emissions[a]	Class[c]		
	River	Great Lakes	Coastal
Sulfur oxides[b] (SO_x as SO_2)			
kg/10^3 liter	3.2	3.2	3.2
lb/10^3 gal	27	27	27
Carbon monoxide			
kg/10^3 liter	12	13	13
lb/10^3 gal	100	110	110
Hydrocarbons			
kg/10^3 liter	6.0	7.0	6.0
lb/10^3 gal	50	59	50
Nitrogen oxides (NO_x as NO_2)			
kg/10^3 liter	33	31	32
lb/10^3 gal	280	260	270

[a] Expressed as function of fuel consumed (based on emission data from Reference 2 and population/usage data from References 11 through 16.

[b] Calculated, not measured. Based on 0.20 percent sulfur content fuel and density of 0.854 kg/liter (7.12 lb/gal) from Reference 17.

[c] Very approximate particulate emission factors from Reference 2 are 470 g/hr (1.04 lb/hr). The reference does not contain sufficient information to calculate fuel-based factors.

quantity of fuel consumed, are presented in Table 3.2.3-4. In some instances, fuel quantities used may not be available, so calculation of emissions based on kilowatt hours (kWh) produced may be necessary. For operating loads in excess of zero percent, the mass emissions (e_l) in kilograms per hour (pounds per hour) are given by:

$$e_l = kle_f \tag{1}$$

where: k = a constant that relates fuel consumption to kilowatt hours,[2]

that is, 3.63×10^{-4} 1000 liters fuel/kWh

or

9.59×10^{-5} 1000 gal fuel/kWh

l = the load, kW

e_f = the fuel-specific emission factor from Table 3.2.3-4, kg/10^3 liter (lb/10^3 gal)

Table 3.2.3-2. EMISSION FACTORS FOR COMMERCIAL STEAMSHIPS–ALL GEOGRAPHIC AREAS
EMISSION FACTOR RATING: D

Pollutant	Fuel and operating mode[a]											
	Residual oil[b]						Distillate oil[b]					
	Hoteling		Cruise		Full		Hoteling		Cruise		Full	
	kg/10^3 liter	lb/10^3 gal	kg/10^3 liter	lb/10^3 gal	kg/10^3 liter	lb/10^3 gal	kg/10^3 liter	lb/10^3 gal	kg/10^3 liter	lb/10^3 gal	kg/10^3 liter	lb/10^3 gal
Particulates[c]	1.20[d]	10.0[d]	2.40	20.0	6.78	56.5	1.8	15	1.78	15	1.78	15
Sulfur oxides (SO_x as SO_2)[e]	19.1S	159S	19.1S	159S	19.1S	159S	17.0S	142S	17.0S	142S	17.0S	142S
Carbon monoxide[c]	Neg[d]	Neg[d]	0.414	3.45	0.872	7.27	0.5	4	0.5	4	0.5	4
Hydrocarbons[c]	0.38[d]	3.2[d]	0.082	0.682	0.206	1.72	0.4	3	0.4	3	0.4	3
Nitrogen oxides (NO_x as NO_2)	4.37	36.4	6.70	55.8	7.63	63.6	2.66	22.2	2.83	23.6	5.34	44.5

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[a] The operating modes are based on the percentage of maximum available power: "hoteling" is 10 to 11 percent of available power, "full" is 100 percent of available power, and "cruise" is an intermediate power (35 to 75 percent, depending on the test organization and vessel tested).

[b] Test organizations used "Navy Special" fuel oil, which is not a true residual oil. No vessel test data were available for residual oil combustion. "Residual" oil results are from References 2, 3, and 5. "Distillate" oil results are from References 3 and 5 only. Exceptions are noted. "Navy Distillate" was used as distillate test fuel.

[c] Particulate, carbon monoxide, and hydrocarbon emission factors for distillate oil combustion are based on stationary boilers (see Section 1.3 of this document).

[d] Reference 18 indicates that carbon monoxide emitted during hoteling is small enough to be considered negligible. This reference also places hydrocarbons at 0.38 kg/10^3 liter (3.2 lb/10^3 gal) and particulate at 1.20 kg/10^3 liter (10.0 lb/10^3 gal). These data are included for completeness only and are not necessarily comparable with other tabulated data.

[e] Emission factors listed are theoretical in that they are based on all the sulfur in the fuel converting to sulfur dioxide. Actual test data from References 3 and 5 confirm the validity of these theoretical factors. "S" is fuel sulfur content in percent.

Table 3.2.3-3. DIESEL VESSEL EMISSION FACTORS BY OPERATING MODE[a]
EMISSION FACTOR RATING: C

Horsepower	Mode	Emissions[b]					
		Carbon monoxide		Hydrocarbons		Nitrogen oxides (NO_x as NO_2)	
		$lb/10^3$ gal	$kg/10^3$ liter	$lb/10^3$ gal	$kg/10^3$ liter	$lb/10^3$ gal	$kg/10^3$ liter
200	Idle	210.3	25.2	391.2	46.9	6.4	0.8
	Slow	145.4	17.4	103.2	12.4	207.8	25.0
	Cruise	126.3	15.1	170.2	20.4	422.9	50.7
	Full	142.1	17.0	60.0	7.2	255.0	30.6
300	Slow	59.0	7.1	56.7	6.8	337.5	40.4
	Cruise	47.3	5.7	51.1	6.1	389.3	46.7
	Full	58.5	7.0	21.0	2.5	275.1	33.0
500	Idle	282.5	33.8	118.1	14.1	99.4	11.9
	Cruise	99.7	11.9	44.5	5.3	338.6	40.6
	Full	84.2	10.1	22.8	2.7	269.2	32.3
600	Idle	171.7	20.6	68.0	8.2	307.1	36.8
	Slow	50.8	6.1	16.6	2.0	251.5	30.1
	Cruise	77.6	9.3	24.1	2.9	349.2	41.8
700	Idle	293.2	35.1	95.8	11.5	246.0	29.5
	Cruise	36.0	4.3	8.8	1.1	452.8	54.2
900	Idle	223.7	26.8	249.1	29.8	107.5	12.9
	2/3	62.2	7.5	16.8	2.0	167.2	20.0
	Cruise	80.9	9.7	17.1	2.1	360.0	43.1
1550	Idle	12.2	1.5	–	–	39.9	4.8
	Cruise	3.3	0.4	0.64	0.1	36.2	4.3
	Full	7.0	0.8	1.64	0.2	37.4	4.5
1580	Slow	122.4	14.7	–	–	371.3	44.5
	Cruise	44.6	5.3	–	–	623.1	74.6
	Full	237.7	28.5	16.8	2.0	472.0	5.7
2500	Slow	59.8	7.2	22.6	2.7	419.6	50.3
	2/3	126.5	15.2	14.7	1.8	326.2	39.1
	Cruise	78.3	9.4	16.8	2.0	391.7	46.9
	Full	95.9	11.5	21.3	2.6	399.6	47.9
3600	Slow	148.5	17.8	60.0	7.2	367.0	44.0
	2/3	28.1	3.4	25.4	3.0	358.6	43.0
	Cruise	41.4	5.0	32.8	4.0	339.6	40.7
	Full	62.4	7.5	29.5	3.5	307.0	36.8

[a] Reference 2.
[b] Particulate and sulfur oxides data are not available.

Table 3.2.3-4. AVERAGE EMISSION FACTORS FOR DIESEL-POWERED ELECTRICAL GENERATORS IN VESSELS[a]
EMISSION FACTOR RATING: C

		Emissions							
		Sulfur oxides (SO_x as SO_2)[d]		Carbon monoxide		Hydrocarbons		Nitrogen oxides (NO_x as NO_2)	
Rated output,[b] kW	Load,[c] % rated output	lb/10^3 gal	kg/10^3 liter	lb/10^3 gal	kg/10^3 liter	lb/10^3 gal	kg/10^3 liter	lb/10^3 gal	kg/10^3 liter
20	0	27	3.2	150	18.0	263	31.5	434	52.0
	25	27	3.2	79.7	9.55	204	24.4	444	53.2
	50	27	3.2	53.4	6.40	144	17.3	477	57.2
	75	27	3.2	28.5	3.42	84.7	10.2	495	59.3
40	0	27	3.2	153	18.3	584	70.0	214	25.6
	25	27	3.2	89.0	10.7	370	44.3	219	26.2
	50	27	3.2	67.6	8.10	285	34.2	226	27.1
	75	27	3.2	64.1	7.68	231	27.7	233	27.9
200	0	27	3.2	134	16.1	135	16.2	142	17.0
	25	27	3.2	97.9	11.7	33.5	4.01	141	16.9
	50	27	3.2	62.3	7.47	17.8	2.13	140	16.8
	75	27	3.2	26.7	3.20	17.5	2.10	137	16.4
500	0	27	3.2	58.4	7.00	209	25.0	153	18.3
	25	27	3.2	53.4	6.40	109	13.0	222	26.6
	50	27	3.2	48.1	5.76	81.9	9.8	293	35.1
	75	27	3.2	43.7	5.24	59.1	7.08	364	43.6

[a] Reference 2.

[b] Maximum rated output of the diesel-powered generator.

[c] Generator electrical output (for example, a 20 kW generator at 50 percent load equals 10 kW output).

[d] Calculated, not measured, based on 0.20 percent fuel sulfur content and density of 0.854 kg/liter (7.12 lb/gal) from Reference 17.

At zero load conditions, mass emission rates (e_1) may be approximated in terms of kg/hr (lb/hr) using the following relationship:

$$e_1 = k l_{rated} e_f \tag{2}$$

where: k = a constant that relates rated output and fuel consumption,

that is, 6.93×10^{-5} 1000 liters fuel/kW

or

1.83×10^{-5} 1000 gal fuel/kW

l_{rated} = the rated output, kW

e_f = the fuel-specific emission factor from Table 3.2.3-4, kg/10^3 liter (lb/10^3 gal)

Pleasure craft. Many of the engine designs used in inboard pleasure craft are also used either in military vessels (diesel) or in highway vehicles (gasoline). Out of a total of 700,000 inboard pleasure craft registered in the United States in 1972, nearly 300,000 were inboard/outdrive. According to sales data, 60 to 70 percent of these inboard/outdrive craft used gasoline-powered automotive engines rated at more than 130 horsepower.[6] The remaining 400,000 pleasure craft used conventional inboard drives that were powered by a variety of powerplants, both gasoline and diesel. Because emission data are not available for pleasure craft, Coast Guard and automotive data[2,19] are used to characterize emission factors for this class of vessels in Table 3.2.3-5.

Military vessels. Military vessels are powered by a wide variety of both diesel and steam power plants. Many of the emission data used in this section are the result of emission testing programs conducted by the U.S. Navy and the U.S. Coast Guard.[1-3,5] A separate table containing data on military vessels is not provided here, but the included tables should be sufficient to calculate approximate military vessel emissions.

TABLE 3.2.3-5. AVERAGE EMISSION FACTORS FOR INBOARD PLEASURE CRAFT[a]

EMISSION FACTOR RATING: D

	Based on fuel consumption				Based on operating time			
	Diesel engine[b]		Gasoline engine[c]					
					Diesel engine[b]		Gasoline engine[c]	
Pollutant	kg/10^3 liter	lb/10^3 gal	kg/10^3 liter	lb/10^3 gal	kg/hr	lb/hr	kg/hr	lb/hr
Sulfur oxides[d] (SO_x as SO_2)	3.2	27	0.77	6.4	–	–	0.008	0.019
Carbon monoxide	17	140	149	1240	–	–	1.69	3.73
Hydrocarbons	22	180	10.3	86	–	–	0.117	0.258
Nitrogen oxides (NO_x as NO_2)	41	340	15.7	131	–	–	0.179	0.394

[a] Average emission factors are based on the duty cycle developed for large outboards (≥ 48 kilowatts or ≥ 65 horsepower) from Reference 7. The above factors take into account the impact of water scrubbing of underwater gasoline engine exhaust, also from Reference 7. All values given are for single engine craft and must be modified for multiple engine vessels.

[b] Based on tests of diesel engines in Coast Guard vessels, Reference 2.

[c] Based on tests of automotive engines, Reference 19. Fuel consumption of 11.4 liter/hr (3 gal/hr) assumed. The resulting factors are only *rough* estimates.

[d] Based on fuel sulfur content of 0.20 percent for diesel fuel and 0.043 percent for gasoline from References 7 and 17. Calculated using fuel density of 0.740 kg/liter (6.17 lb/gal) for gasoline and 0.854 kg/liter (7.12 lb/gal) for diesel fuel.

References for Section 3.2.3

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3.2.4 Outboard-Powered Vessels

by David S. Kircher

3.2.4.1 General – Most of the approximately 7 million outboard motors in use in the United States are 2-stroke engines with an average available horsepower of about 25. Because of the predominately leisure-time use of outboard motors, emissions related to their operation occur primarily during nonworking hours, in rural areas, and during the three summer months. Nearly 40 percent of the outboards are operated in the states of New York, Texas, Florida, Michigan, California, and Minnesota. This distribution results in the concentration of a large portion of total nationwide outboard emissions in these states.[1]

3.2.4.2 Emissions – Because the vast majority of outboards have underwater exhaust, emission measurement is very difficult. The values presented in Table 3.2.4-1 are the approximate atmospheric emissions from outboards. These data are based on tests of four outboard motors ranging from 4 to 65 horsepower.[1] The emission results from these motors are a composite based on the nationwide breakdown of outboards by horsepower. Emission factors are presented two ways in this section: in terms of fuel use and in terms of work output (horsepower hour). The selection of the factor used depends on the source inventory data available. Work output factors are used when the number of outboards in use is available. Fuel-specific emission factors are used when fuel consumption data are obtainable.

Table 3.2.4-1. AVERAGE EMISSION FACTORS FOR OUTBOARD MOTORS[a]
EMISSION FACTOR RATING: B

	Based on fuel consumption		Based on work output[c]	
Pollutant[b]	lb/10^3 gal	kg/10^3 liter	g/hphr	g/metric hphr
Sulfur oxides[d] (SO_x as SO_2)	6.4	0.77	0.49	0.49
Carbon monoxide	3300	400	250	250
Hydrocarbons[e]	1100	130	85	85
Nitrogen oxides (NO_x as NO_2)	6.6	0.79	0.50	0.50

[a] Reference 1. Data in this table are emissions to the atmosphere. A portion of the exhaust remains behind in the water.

[b] Particulate emission factors are not available because of the problems involved with measurement from an underwater exhaust system but are considered negligible.

[c] Horsepower hours are calculated by multiplying the average power produced during the hours of usage by the population of outboards in a given area. In the absence of data specific to a given geographic area, the hphr value can be estimated using average nationwide values from Reference 1. Reference 1 reports the average power produced (not the available power) as 9.1 hp and the average annual usage per engine as 50 hours. Thus, hphr = (number of outboards) (9.1 hp) (50 hours/outboard-year). Metric hphr = 0.9863 hphr.

[d] Based on fuel sulfur content of 0.043 percent from Reference 2 and on a density of 6.17 lb/gal.

[e] Includes exhaust hydrocarbons only. No crankcase emissions occur because the majority of outboards are 2-stroke engines that use crankcase induction. Evaporative emissions are limited by the widespread use of unvented tanks.

References for sections 3.2.4

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3.2.5 Small, General Utility Engines

Revised by Charles C. Masser

3.2.5.1 General–This category of engines comprises small 2-stroke and 4-stroke, air-cooled, gasoline-powered motors. Examples of the uses of these engines are: lawnmowers, small electric generators, compressors, pumps, minibikes, snowthrowers, and garden tractors. This category does *not* include motorcycles, outboard motors, chain saws, and snowmobiles, which are either included in other parts of this chapter or are not included because of the lack of emission data.

Approximately 89 percent of the more than 44 million engines of this category in service in the United States are used in lawn and garden applications.[1]

3.2.5.2 Emissions–Emissions from these engines are reported in Table 3.2.5-1. For the purpose of emission estimation, engines in this category have been divided into lawn and garden (2-stroke), lawn and garden (4-stroke), and miscellaneous (4-stroke). Emission factors are presented in terms of horsepower hours, annual usage, and fuel consumption.

References for Section 3.2.5

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Table 3.2.5-1. EMISSION FACTORS FOR SMALL, GENERAL UTILITY ENGINES[a,b]
EMISSION FACTOR RATING: B

Engine	Sulfur oxides[c] (SO_x as SO_2)	Particulate	Carbon monoxide	Hydrocarbons		Nitrogen oxides (NO_x as NO_2)	Aldehydes (HCHO)
				Exhaust	Evaporative[d]		
2-Stroke, lawn and garden							
g/hphr	0.54	7.1	486	214	–	1.58	2.04
g/metric hphr	0.54	7.1	486	214	–	1.58	2.04
g/gal of fuel	1.80	23.6	1,618	713	–	5.26	6.79
g/unit-year	38	470	33,400	14,700	113	108	140
4-Stroke, lawn and garden							
g/hphr	0.37	0.44	279	23.2	–	3.17	0.49
g/metric hphr	0.37	0.44	279	23.2	–	3.17	0.49
g/gal of fuel	2.37	2.82	1,790	149	–	20.3	3.14
g/unit-year	26	31	19,100	1,590	113	217	34
4-Stroke miscellaneous							
g/hphr	0.39	0.44	250	15.2	–	4.97	0.47
g/metric hphr	0.39	0.44	250	15.2	–	4.97	0.47
g/gal of fuel	2.45	2.77	1,571	95.5	–	31.2	2.95
g/unit-year	30	34	19,300	1,170	290	384	36

[a] Reference 2.

[b] Values for g/unit-year were calculated assuming an annual usage of 50 hours and a 40 percent load factor. Factors for g/hphr can be used in instances where annual usages, load factors, and rated horsepower are known. Horsepower hours are the product of the usage in hours, the load factor, and the rated horsepower.

[c] Values calculated, not measured, based on the use of 0.043 percent sulfur content fuel.

[d] Values calculated from annual fuel consumption. Evaporative losses from storage and filling operations are not included (see Chapter 4).

3.2.6 Agricultural Equipment

by David S. Kircher

3.2.6.1 General – Farm equipment can be separated into two major categories: wheeled tractors and other farm machinery. In 1972, the wheeled tractor population on farms consisted of 4.5 million units with an average power of approximately 34 kilowatts (45 horsepower). Approximately 30 percent of the total population of these tractors is powered by diesel engines. The average diesel tractor is more powerful than the average gasoline tractor, that is, 52 kW (70 hp) versus 27 kW (36 hp).[1] A considerable amount of population and usage data is available for farm tractors. For example, the Census of Agriculture reports the number of tractors in use for each county in the U.S.[2] Few data are available on the usage and numbers of non-tractor farm equipment, however. Self-propelled combines, forage harvesters, irrigation pumps, and auxiliary engines on pull-type combines and balers are examples of non-tractor agricultural uses of internal combustion engines. Table 3.2.6-1 presents data on this equipment for the U.S.

3.2.6.2 Emissions – Emission factors for wheeled tractors and other farm machinery are presented in Table 3.2.6-2. Estimating emissions from the time-based emission factors–grams per hour (g/hr) and pounds per hour (lb/hr)–requires an average usage value in hours. An approximate figure of 550 hours per year may be used or, on the basis of power, the relationship, usage in hours = 450 + 5.24 (kW - 37.2) or usage in hours = 450 + 3.89 (hp - 50) may be employed.[1]

The best emissions estimates result from the use of "brake specific" emission factors (g/kWh or g/hphr). Emissions are the product of the brake specific emission factor, the usage in hours, the power available, and the load factor (power used divided by power available). Emissions are also reported in terms of fuel consumed.

Table 3.2.6-1. SERVICE CHARACTERISTICS OF FARM EQUIPMENT (OTHER THAN TRACTORS)[a]

Machine	Units in service, $\times 10^3$	Typical size	Typical power		Percent gasoline	Percent diesel
			kW	hp		
Combine, self-propelled	434	4.3 m (14 ft)	82	110	50	50
Combine, pull type	289	2.4 m (8 ft)	19	25	100	0
Corn pickers and picker-shellers	687	2-row	–[b]	–	–	–
Pick-up balers	655	5400 kg/hr (6 ton/hr)	30	40	100	0
Forage harvesters	295	3.7 m (12 ft) or 3-row	104	140	0	100
Miscellaneous	1205	–	22	30	50	50

[a] Reference 1.

[b] Unpowered.

Table 3.2.6-2. EMISSION FACTORS FOR WHEELED FARM TRACTORS AND NON-TRACTOR AGRICULTURAL EQUIPMENT[a]
EMISSION FACTOR RATING: C

Pollutant	Diesel farm tractor	Gasoline farm tractor	Diesel farm equipment (non-tractor)	Gasoline farm equipment (non-tractor)
Carbon monoxide				
g/hr	161	3,380	95.2	4,360
lb/hr	0.355	7.46	0.210	9.62
g/kWh	4.48	192	5.47	292
g/hphr	3.34	143	4.08	218
$kg/10^3$ liter	14.3	391	16.7	492
$lb/10^3$ gal	119	3,260	139	4,100
Exhaust hydrocarbons				
g/hr	77.8	128	38.6	143
lb/hr	0.172	0.282	0.085	0.315
g/kWh	2.28	7.36	2.25	9.63
g/hphr	1.70	5.49	1.68	7.18
$kg/10^3$ liter	7.28	15.0	6.85	16.2
$lb/10^3$ gal	60.7	125	57.1	135
Crankcase hydrocarbons[b]				
g/hr	–	26.0	–	28.6
lb/hr	–	0.057	–	0.063
g/kWh	–	1.47	–	1.93
g/hphr	–	1.10	–	1.44
$kg/10^3$ liter	–	3.01	–	3.25
$lb/10^3$ gal	–	25.1	–	27.1
Evaporative hydrocarbons[b]				
g/unit-year	–	15,600	–	1,600
lb/unit-year	–	34.4	–	3.53
Nitrogen oxides (NO_x as NO_2)				
g/hr	452	157	210	105
lb/hr	0.996	0.346	0.463	0.231
g/kWh	12.6	8.88	12.11	7.03
g/hphr	9.39	6.62	9.03	5.24
$kg/10^3$ liter	40.2	18.1	36.8	11.8
$lb/10^3$ gal	335	151	307	98.5
Aldehydes (RCHO as HCHO)				
g/hr	16.3	7.07	7.23	4.76
lb/hr	0.036	0.016	0.016	0.010
g/kWh	0.456	0.402	0.402	0.295
g/hphr	0.340	0.300	0.30	0.220
$kg/10^3$ liter	1.45	0.821	1.22	0.497
$lb/10^3$ gal	12.1	6.84	10.2	4.14
Sulfur oxides[c] (SO_x as SO_2)				
g/hr	42.2	5.56	21.7	6.34
lb/hr	0.093	0.012	0.048	0.014

Table 3.2.6-2. (continued). EMISSION FACTORS FOR WHEELED FARM TRACTORS AND NON-TRACTOR AGRICULTURAL EQUIPMENT[a]
EMISSION FACTOR RATING: C

Pollutant	Diesel farm tractor	Gasoline farm tractor	Diesel farm equipment (non-tractor)	Gasoline farm equipment (non-tractor)
g/kWh	1.17	0.312	1.23	0.377
g/hphr	0.874	0.233	0.916	0.281
kg/10^3 liter	3.74	0.637	3.73	0.634
lb/10^3 gal	31.2	5.31	31.1	5.28
Particulate				
g/hr	61.8	8.33	34.9	7.94
lb/hr	0.136	0.018	0.077	0.017
g/kWh	1.72	0.471	2.02	0.489
g/hphr	1.28	0.361	1.51	0.365
kg/10^3 liter	5.48	0.960	6.16	0.823
lb/10^3 gal	45.7	8.00	51.3	6.86

[a] Reference 1.

[b] Crankcase and evaporative emissions from diesel engines are considered negligible.

[c] Not measured. Calculated from fuel sulfur content of 0.043 percent and 0.22 percent for gasoline-powered and diesel-powered equipment, respectively.

References for Section 3.2.6

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2. County Farm Reports. U.S. Census of Agriculture. U.S. Department of Agriculture. Washington, D.C.

3.2.7 Heavy-Duty Construction Equipment

by David S. Kircher

3.2.7.1 General – Because few sales, population, or usage data are available for construction equipment, a number of assumptions were necessary in formulating the emission factors presented in this section.[1] The useful life of construction equipment is fairly short because of the frequent and severe usage it must endure. The annual usage of the various categories of equipment considered here ranges from 740 hours (wheeled tractors and rollers) to 2000 hours (scrapers and off-highway trucks). This high level of use results in average vehicle lifetimes of only 6 to 16 years. The equipment categories in this section include: tracklaying tractors, tracklaying shovel loaders, motor graders, scrapers, off-highway trucks, wheeled loaders, wheeled tractors, rollers, wheeled dozers, and miscellaneous machines. The latter category contains a vast array of less numerous mobile and semi-mobile machines used in construction, such as, belt loaders, cranes, pumps, mixers, and generators. With the exception of rollers, the majority of the equipment within each category is diesel-powered.

3.2.7.2 Emissions – Emission factors for heavy-duty construction equipment are reported in Table 3.2.7-1 for diesel engines and in Table 3.2.7-2 for gasoline engines. The factors are reported in three different forms–on the basis of running time, fuel consumed, and power consumed. In order to estimate emissions from time-based emission factors, annual equipment usage in hours must be estimated. The following estimates of use for the equipment listed in the tables should permit reasonable emission calculations.

Category	Annual operation, hours/year
Tracklaying tractors	1050
Tracklaying shovel loaders	1100
Motor graders	830
Scrapers	2000
Off-highway trucks	2000
Wheeled loaders	1140
Wheeled tractors	740
Rollers	740
Wheeled dozers	2000
Miscellaneous	1000

The best method for calculating emissions, however, is on the basis of "brake specific" emission factors (g/kWh or g/hphr). Emissions are calculated by taking the product of the brake specific emission factor, the usage in hours, the power available (that is, rated power), and the load factor (the power actually used divided by the power available).

References for Section 3.2.7

1. Hare, C. T. and K. J. Springer. Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines – Final Report. Part 5: Heavy-Duty Farm, Construction, and Industrial Engines. Southwest Research Institute, San Antonio, Tex. Prepared for Environmental Protection Agency, Research Triangle Park, N.C., under Contract No. EHS 70-108. October 1973. 105 p.

2. Hare, C. T. Letter to C. C. Masser of Environmental Protection Agency, Research Triangle Park, N.C., concerning fuel-based emission rates for farm, construction, and industrial engines. San Antonio, Tex. January 14, 1974. 4 p.

Table 3.2.7-1. EMISSION FACTORS FOR HEAVY-DUTY, DIESEL-POWERED CONSTRUCTION EQUIPMENT[a]

EMISSION FACTOR RATING: C

Pollutant	Tracklaying tractor	Wheeled tractor	Wheeled dozer	Scraper	Motor grader
Carbon monoxide					
g/hr	175.	973.	335.	660.	97.7
lb/hr	0.386	2.15	0.739	1.46	0.215
g/kWh	3.21	5.90	2.45	3.81	2.94
g/hphr	2.39	4.40	1.83	2.84	2.19
kg/10^3 liter	10.5	19.3	7.90	11.8	9.35
lb/10^3 gal	87.5	161.	65.9	98.3	78.0
Exhaust hydrocarbons					
g/hr	50.1	67.2	106.	284.	24.7
lb/hr	0.110	0.148	0.234	0.626	0.054
g/kWh	0.919	1.86	0.772	1.64	0.656
g/hphr	0.685	1.39	0.576	1.22	0.489
kg/10^3 liter	3.01	6.10	2.48	5.06	2.09
lb/10^3 gal	25.1	50.9	20.7	42.2	17.4
Nitrogen oxides (NO_x as NO_2)					
g/hr	665.	451.	2290.	2820.	478.
lb/hr	1.47	0.994	5.05	6.22	1.05
g/kWh	12.2	12.5	16.8	16.2	14.1
g/hphr	9.08	9.35	12.5	12.1	10.5
kg/10^3 liter	39.8	41.0	53.9	50.2	44.8
lb/10^3 gal	332.	342.	450.	419.	374.
Aldehydes (RCHO as HCHO)					
g/hr	12.4	13.5	29.5	65.	5.54
lb/hr	0.027	0.030	0.065	0.143	0.012
g/kWh	0.228	0.378	0.215	0.375	0.162
g/hphr	0.170	0.282	0.160	0.280	0.121
kg/10^3 liter	0.745	1.23	0.690	1.16	0.517
lb/10^3 gal	6.22	10.3	5.76	9.69	4.31
Sulfur oxides (SO_x as SO_2)					
g/hr	62.3	40.9	158.	210.	39.0
lb/hr	0.137	0.090	0.348	0.463	0.086
g/kWh	1.14	1.14	1.16	1.21	1.17
g/hphr	0.851	0.851	0.867	0.901	0.874
kg/10^3 liter	3.73	3.73	3.74	3.74	3.73
lb/10^3 gal	31.1	31.1	31.2	31.2	31.1
Particulate					
g/hr	50.7	61.5	75.	184.	27.7
lb/hr	0.112	0.136	0.165	0.406	0.061
g/kWh	0.928	1.70	0.551	1.06	0.838
g/hphr	0.692	1.27	0.411	0.789	0.625
kg/10^3 liter	3.03	5.57	1.77	3.27	2.66
lb/10^3 gal	25.3	46.5	14.8	27.3	22.2

[a] References 1 and 2.

Table 3.2.7-1 (continued). EMISSION FACTORS FOR HEAVY-DUTY, DIESEL-POWERED CONSTRUCTION EQUIPMENT[a]
EMISSION FACTOR RATING: C

Pollutant	Wheeled loader	Tracklaying loader	Off-Highway truck	Roller	Miscellaneous
Carbon monoxide					
g/hr	251.	72.5	610.	83.5	188.
lb/hr	0.553	0.160	1.34	0.184	0.414
g/kWh	3.51	2.41	3.51	4.89	3.78
g/hphr	2.62	1.80	2.62	3.65	2.82
kg/10^3 liter	11.4	7.90	11.0	13.7	11.3
lb/10^3 gal	95.4	65.9	92.2	114.	94.2
Exhaust hydrocarbons					
g/hr	84.7	14.5	198.	24.7	71.4
lb/hr	0.187	0.032	0.437	0.054	0.157
g/kWh	1.19	0.485	1.14	1.05	1.39
g/hphr	0.888	0.362	0.853	0.781	1.04
kg/10^3 liter	3.87	1.58	3.60	2.91	4.16
lb/10^3 gal	32.3	13.2	30.0	24.3	34.7
Nitrogen oxides (NO_x as NO_2)					
g/hr	1090.	265.	3460.	474.	1030.
lb/hr	2.40	0.584	7.63	1.04	2.27
g/kWh	15.0	8.80	20.0	21.1	19.8
g/hphr	11.2	6.56	14.9	15.7	14.8
kg/10^3 liter	48.9	28.8	62.8	58.5	59.2
lb/10^3 gal	408.	240.	524.	488.	494.
Aldehydes (RCHO as HCHO)					
g/hr	18.8	4.00	51.0	7.43	13.9
lb/hr	0.041	0.009	0.112	0.016	0.031
g/kWh	0.264	0.134	0.295	0.263	0.272
g/hphr	0.197	0.100	0.220	0.196	0.203
kg/10^3 liter	0.859	0.439	0.928	0.731	0.813
lb/10^3 gal	7.17	3.66	7.74	6.10	6.78
Sulfur oxides (SO_x as SO_2)					
g/hr	82.5	34.4	206.	30.5	64.7
lb/hr	0.182	0.076	0.454	0.067	0.143
g/kWh	1.15	1.14	1.19	1.34	1.25
g/hphr	0.857	0.853	0.887	1.00	0.932
kg/10^3 liter	3.74	3.74	3.74	3.73	3.73
lb/10^3 gal	31.2	31.2	31.2	31.1	31.1
Particulate					
g/hr	77.9	26.4	116.	22.7	63.2
lb/hr	0.172	0.058	0.256	0.050	0.139
g/kWh	1.08	0.878	0.673	1.04	1.21
g/hphr	0.805	0.655	0.502	0.778	0.902
kg/10^3 liter	3.51	2.88	2.12	2.90	3.61
lb/10^3 gal	29.3	24.0	17.7	24.2	30.1

[a] References 1 and 2.

Table 3.2.7-2. EMISSION FACTORS FOR HEAVY-DUTY GASOLINE-POWERED CONSTRUCTION EQUIPMENT[a]
EMISSION FACTOR RATING: C

Pollutant	Wheeled tractor	Motor grader	Wheeled loader	Roller	Miscel-laneous
Carbon monoxide					
g/hr	4320.	5490.	7060.	6080.	7720.
lb/hr	9.52	12.1	15.6	13.4	17.0
g/kWh	190.	251.	219.	271.	266.
g/hphr	142.	187.	163.	202.	198.
kg/10^3 liter	389.	469.	435.	460.	475.
lb/10^3 gal	3250.	3910.	3630.	3840.	3960.
Exhaust hydrocarbons					
g/hr	164.	186.	241.	277.	254.
lb/hr	0.362	0.410	0.531	0.611	0.560
g/kWh	7.16	8.48	7.46	12.40	8.70
g/hphr	5.34	6.32	5.56	9.25	6.49
kg/10^3 liter	14.6	15.8	14.9	21.1	15.6
lb/10^3 gal	122.	132.	124.	176.	130.
Evaporative hydrocarbons[b]					
g/hr	30.9	30.0	29.7	28.2	25.4
lb/hr	0.0681	0.0661	0.0655	0.0622	0.0560
Crankcase hydrocarbons[b]					
g/hr	32.6	37.1	48.2	55.5	50.7
lb/hr	0.0719	0.0818	0.106	0.122	0.112
Nitrogen oxides (NO_x as NO_2)					
g/hr	195.	145.	235.	164.	187.
lb/hr	0.430	0.320	0.518	0.362	0.412
g/kWh	8.54	6.57	7.27	7.08	6.42
g/hphr	6.37	4.90	5.42	5.28	4.79
kg/10^3 liter	17.5	12.2	14.5	12.0	11.5
lb/10^3 gal	146.	102.	121.	100.	95.8
Aldehydes (RCHO as HCHO)					
g/hr	7.97	8.80	9.65	7.57	9.00
lb/hr	0.0176	0.0194	0.0213	0.0167	0.0198
g/kWh	0.341	0.386	0.298	0.343	0.298
g/hphr	0.254	0.288	0.222	0.256	0.222
kg/10^3 liter	0.697	0.721	0.593	0.582	0.532
lb/10^3 gal	5.82	6.02	4.95	4.86	4.44
Sulfur oxides (SO_x as SO_2)					
g/hr	7.03	7.59	10.6	8.38	10.6
lb/hr	0.0155	0.0167	0.0234	0.0185	0.0234
g/kWh	0.304	0.341	0.319	0.373	0.354
g/hphr	0.227	0.254	0.238	0.278	0.264
kg/10^3 liter	0.623	0.636	0.636	0.633	0.633
lb/10^3 gal	5.20	5.31	5.31	5.28	5.28

Table 3.2.7-2. (continued). EMISSION FACTORS FOR HEAVY-DUTY GASOLINE-POWERED CONSTRUCTION EQUIPMENT[a]
EMISSION FACTOR RATING: C

Pollutant	Wheeled tractor	Motor grader	Wheeled loader	Roller	Miscel-laneous
Particulate					
g/hr	10.9	9.40	13.5	11.8	11.7
lb/hr	0.0240	0.0207	0.0298	0.0260	0.0258
g/kWh	0.484	0.440	0.421	0.527	0.406
g/hphr	0.361	0.328	0.314	0.393	0.303
kg/10^3 liter	0.991	0.822	0.839	0.895	0.726
lb/10^3 gal	8.27	6.86	7.00	7.47	6.06

[a] References 1 and 2.

[b] Evaporative and crankcase hydrocarbons based on operating time only (Reference 1).

3.2.8 Snowmobiles

by Charles C. Masser

3.2.8.1 General – In order to develop emission factors for snowmobiles, mass emission rates must be known, and operating cycles representative of usage in the field must be either known or assumed. Extending the applicability of data from tests of a few vehicles to the total snowmobile population requires additional information on the composition of the vehicle population by engine size and type. In addition, data on annual usage and total machine population are necessary when the effect of this source on national emission levels is estimated.

An accurate determination of the number of snowmobiles in use is quite easily obtained because most states require registration of the vehicles. The most notable features of these registration data are that almost 1.5 million sleds are operated in the United States, that more than 70 percent of the snowmobiles are registered in just four states (Michigan, Minnesota, Wisconsin, and New York), and that only about 12 percent of all snowmobiles are found in areas outside the northeast and northern midwest.

3.2.8.2 Emissions – Operating data on snowmobiles are somewhat limited, but enough are available so that an attempt can be made to construct a representative operating cycle. The required end products of this effort are time-based weighting factors for the speed/load conditions at which the test engines were operated; use of these factors will permit computation of "cycle composite" mass emissions, power consumption, fuel consumption, and specific pollutant emissions.

Emission factors for snowmobiles were obtained through an EPA-contracted study[1] in which a variety of snowmobile engines were tested to obtain exhaust emissions data. These emissions data along with annual usage data were used by the contractor to estimate emission factors and the nationwide emission impact of this pollutant source.

To arrive at average emission factors for snowmobiles, a reasonable estimate of average engine size was necessary. Weighting the size of the engine to the degree to which each engine is assumed to be representative of the total population of engines in service resulted in an estimated average displacement of 362 cubic centimeters (cm^3).

The speed/load conditions at which the test engines were operated represented, as closely as possible, the normal operation of snowmobiles in the field. Calculations using the fuel consumption data obtained during the tests and the previously approximated average displacement of 362 cm^3 resulted in an estimated average fuel consumption of 0.94 gal/hr.

To compute snowmobile emission factors on a gram per unit year basis, it is necessary to know not only the emission factors but also the annual operating time. Estimates of this usage are discussed in Reference 1. On a national basis, however, average snowmobile usage can be assumed to be 60 hours per year. Emission factors for snowmobiles are presented in Table 3.2.8-1.

References for Section 3.2.8

1. Hare, C. T. and K. J. Springer. Study of Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines. Final Report. Part 7: Snowmobiles. Southwest Research Institute, San Antonio, Tex. Prepared for Environmental Protection Agency, Research Triangle Park, N.C., under Contract No. EHS 70-108. April 1974.

Table 3.2.8-1. EMISSION FACTORS FOR SNOWMOBILES
EMISSION FACTOR RATING: B

Pollutant	Emissions			
	g/unit-year[a]	g/gal[b]	g/liter[b]	g/hr[b]
Carbon monoxide	58,700	1,040.	275.	978.
Hydrocarbons	37,800	670.	177.	630.
Nitrogen oxides	600	10.6	2.8	10.0
Sulfur oxides[c]	51	0.90	0.24	0.85
Solid particulate	1,670	29.7	7.85	27.9
Aldehydes (RCHO)	552	9.8	2.6	9.2

[a] Based on 60 hours of operation per year and 362 cm^3 displacement.

[b] Based on 362 cm^3 displacement and average fuel consumption of 0.94 gal/hr.

[c] Based on sulfur content of 0.043 percent by weight.

3.3 OFF-HIGHWAY, STATIONARY SOURCES

by David S. Kircher and
Charles C. Masser

In general, engines included in this category are internal combustion engines used in applications similar to those associated with external combustion sources (see Chapter 1). The major engines within this category are gas turbines and large, heavy-duty, general utility reciprocating engines. Emission data currently available for these engines are limited to gas turbines and natural-gas-fired, heavy-duty, general utility engines. Most stationary internal combustion engines are used to generate electric power, to pump gas or other fluids, or to compress air for pneumatic machinery.

3.3.1 Stationary Gas Turbines for Electric Utility Power Plants

3.3.1.1 General – Stationary gas turbines find application in electric power generators, in gas pipeline pump and compressor drives, and in various process industries. The majority of these engines are used in electrical generation for continuous, peaking, or standby power.[1] The primary fuels used are natural gas and No. 2 (distillate) fuel oil, although residual oil is used in a few applications.

3.3.1.2 Emissions – Data on gas turbines were gathered and summarized under an EPA contract.[2] The contractor found that several investigators had reported data on emissions from gas turbines used in electrical generation but that little agreement existed among the investigators regarding the terms in which the emissions were expressed. The efforts represented by this section include acquisition of the data and their conversion to uniform terms. Because many sets of measurements reported by the contractor were not complete, this conversion often involved assumptions on engine air flow or fuel flow rates (based on manufacturers' data). Another shortcoming of the available information was that relatively few data were obtained at loads below maximum rated (or base) load.

Available data on the population and usage of gas turbines in electric utility power plants are fairly extensive, and information from the various sources appears to be in substantial agreement. The source providing the most complete information is the Federal Power Commission, which requires major utilities (electric revenues of $1 million or more) to submit operating and financial data on an annual basis. Sawyer and Farmer[3] employed these data to develop statistics on the use of gas turbines for electric generation in 1971. Although their report involved only the major, publicly owned utilities (not the private or investor-owned companies), the statistics do appear to include about 87 percent of the gas turbine power used for electric generation in 1971.

Of the 253 generating stations listed by Sawyer and Farmer, 137 have more than one turbine-generator unit. From the available data, it is not possible to know how many hours *each* turbine was operated during 1971 for these multiple-turbine plants. The remaining 116 (single-turbine) units, however, were operated an average of 1196 hours during 1971 (or 13.7 percent of the time), and their average load factor (percent of rated load) during operation was 86.8 percent. This information alone is not adequate for determining a representative operating pattern for electric utility turbines, but it should help prevent serious errors.

Using 1196 hours of operation per year and 250 starts per year as normal, the resulting average operating day is about 4.8 hours long. One hour of no-load time per day would represent about 21 percent of operating time, which is considered somewhat excessive. For economy considerations, turbines are not run at off-design conditions any longer than necessary, so time spent at intermediate power points is probably minimal. The bulk of turbine operation must be at base or peak load to achieve the high load factor already mentioned.

If it is assumed that time spent at off-design conditions includes 15 percent at zero load and 2 percent each at 25 percent, 50 percent, and 75 percent load, then the percentages of operating time at rated load (100 percent) and peak load (assumed to be 125 percent of rated) can be calculated to produce an 86.8 percent load factor. These percentages turn out to be 19 percent at peak load and 60 percent at rated load; the postulated cycle based on this line of reasoning is summarized in Table 3.3.1-1.

Table 3.3.1-1. TYPICAL OPERATING CYCLE FOR ELECTRIC UTILITY TURBINES

Condition, % of rated power	Percent operating time spent at condition	Time at condition based on 4.8-hr day		Contribution to load factor at condition
		hours	minutes	
0	15	0.72	43	0.00 x 0.15 = 0.0
25	2	0.10	6	0.25 x 0.02 = 0.005
50	2	0.10	6	0.50 x 0.02 = 0.010
75	2	0.10	6	0.75 x 0.02 = 0.015
100 (base)	60	2.88	173	1.0 x 0.60 = 0.60
125 (peak)	19	0.91	55	1.25 x 0.19 = 0.238
		4.81	289	Load factor = 0.868

The operating cycle in Table 3.3.1-1 is used to compute emission factors, although it is only an estimate of actual operating patterns.

Table 3.3.1-2. COMPOSITE EMISSION FACTORS FOR 1971 POPULATION OF ELECTRIC UTILITY TURBINES
EMISSION FACTOR RATING: B

Time basis	Nitrogen oxides	Hydro-carbons	Carbon Monoxide	Partic-ulate	Sulfur oxides
Entire population					
lb/hr rated load[a]	8.84	0.79	2.18	0.52	0.33
kg/hr rated load	4.01	0.36	0.99	0.24	0.15
Gas-fired only					
lb/hr rated load	7.81	0.79	2.18	0.27	0.098
kg/hr rated load	3.54	0.36	0.99	0.12	0.044
Oil-fired only					
lb/hr rated load	9.60	0.79	2.18	0.71	0.50
kg/hr rated load	4.35	0.36	0.99	0.32	0.23
Fuel basis					
Gas-fired only					
lb/10^6 ft^3 gas	413.	42.	115.	14.	5.2
kg/10^6 m^3 gas	6615.	673.	1842.	224.	83.
Oil-fired only					
lb/10^3 gal oil	67.8	5.57	15.4	5.0	3.5
kg/10^3 liter oil	8.13	0.668	1.85	0.60	0.42

[a] Rated load expressed in megawatts.

Table 3.3.1-2 is the resultant composite emission factors based on the operating cycle of Table 3.3.1-1 and the 1971 population of electric utility turbines.

Different values for time at base and peak loads are obtained by changing the total time at lower loads (0 through 75 percent) or by changing the distribution of time spent at lower loads. The cycle given in Table 3.3.1-1 seems reasonable, however, considering the fixed load factor and the economies of turbine operation. Note that the cycle determines *only* the importance of each load condition in computing composite emission factors for each type of turbine, *not* overall operating hours.

The top portion of Table 3.3.1-2 gives separate factors for gas-fired and oil-fired units, and the bottom portion gives fuel-based factors that can be used to estimate emission rates when overall fuel consumption data are available. Fuel-based emission factors on a mode basis would also be useful but present fuel consumption data are not adequate for this purpose.

References for Section 3.3.1

1. O'Keefe, W. and R. G. Schwieger. Prime Movers. Power. *115*(11): 522-531. November 1971.

2. Hare, C. T. and K. J. Springer. Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines. Final Report. Part 6: Gas Turbine Electric Utility Power Plants. Southwest Research Institute, San Antonio, Tex. Prepared for Environmental Protection Agency, Research Triangle Park, N.C., under Contract No. EHS 70-108, February 1974.

3. Sawyer, V. W. and R. C. Farmer. Gas Turbines in U.S. Electric Utilities. Gas Turbine International. January – April 1973.

3.3.2 Heavy-Duty, Natural-Gas-Fired Pipeline Compressor Engines

by Susan Sercer
Alan Burgess
Tom Lahre

3.3.2.1 General[1] – Engines in the natural gas industry are used primarily to power compressors used for pipeline transportation, field gathering (collecting gas from wells), underground storage, and gas processing plant applications. Pipeline engines are concentrated in the major gas producing states (such as those along the Gulf Coast) and along the major gas pipelines. Both reciprocating engines and gas turbines are utilized, but the trend has been toward use of large gas turbines. Gas turbines emit considerably fewer pollutants than do reciprocating engines; however, reciprocating engines are generally more efficient in their use of fuel.

3.3.2.2 Emissions and Controls[1,2] – The primary pollutant of concern is NO_x, which readily forms in the high temperature, pressure, and excess air environment found in natural-gas-fired compressor engines. Lesser amounts of carbon monoxide and hydrocarbons are emitted, although for each unit of natural gas burned, compressor engines (particularly reciprocating engines) emit significantly more of these pollutants than do external combustion boilers. Sulfur oxides emissions are proportional to the sulfur content of the fuel and will usually be quite low because of the negligible sulfur content of most pipeline gas.

The major variables affecting NO_x emissions from compressor engines include the air fuel ratio, engine load (defined as the ratio of the operating horsepower divided by the rated horsepower), intake (manifold) air temperature, and absolute humidity. In general, NO_x emissions increase with increasing load and intake air temperature and decrease with increasing absolute humidity and air fuel ratio. (The latter already being, in most compressor engines, on the "lean" side of that air fuel ratio at which maximum NO_x formation occurs.) Quantitative estimates of the effects of these variables are presented in Reference 2.

Because NO_x is the primary pollutant of significance emitted from pipeline compressor engines, control measures to date have been directed mainly at limiting NO_x emissions. For gas turbines, the most effective method of controlling NO_x emissions is the injection of water into the combustion chamber. Nitrogen oxides reductions as high as 80 percent can be achieved by this method. Moreover, water injection results in only nominal reductions in overall turbine efficiency. Steam injection can also be employed, but the resulting NO_x reductions may not be as great as with water injection, and it has the added disadvantage that a supply of steam must be readily available. Exhaust gas recirculation, wherein a portion of the exhaust gases is recirculated back into the intake manifold, may result in NO_x reductions of up to 50 percent. This technique, however, may not be practical in many cases because the recirculated gases must be cooled to prevent engine malfunction. Other combustion modifications, designed to reduce the temperature and/or residence time of the combustion gases, can also be effective in reducing NO_x emissions by 10 to 40 percent in specific gas turbine units.

For reciprocating gas-fired engines, the most effective NO_x control measures are those that change the air-fuel ratio. Thus, changes in engine torque, speed, intake air temperature, etc., that in turn increase the air-fuel ratio, may all result in lower NO_x emissions. Exhaust gas recirculation may also be effective in lowering NO_x emissions although, as with turbines, there are practical limits because of the large quantities of exhaust gas that must be cooled. Available data suggest that other NO_x control measures, including water and steam injection, have only limited application to reciprocating gas-fired engines.

Emission factors for natural-gas-fired pipeline compressor engines are presented in Table 3.3.2-1.

Table 3.3.2-1. EMISSION FACTORS FOR HEAVY-DUTY, NATURAL-GAS-FIRED PIPELINE COMPRESSOR ENGINES[a]

EMISSION FACTOR RATING: A

	Nitrogen oxides (as NO_2)[b]	Carbon monoxide	Hydrocarbons (as C)[c]	Sulfur dioxide[d]	Particulate[e]
Reciprocating engines					
lb/10^3 hp-hr	24	3.1	9.7	0.004	NA
g/hp-hr	11	1.4	4.4	0.002	NA
g/kW-hr	15	1.9	5.9	0.003	NA
lb/10^6 scf[f]	3,400	430	1,400	0.6	NA
kg/10^6 $\underline{N}m^3$[f]	55,400	7,020	21,800	9.2	NA
Gas turbines					
lb/10^3 hp-hr	2.9	1.1	0.2	0.004	NA
g/hp-hr	1.3	0.5	0.1	0.002	NA
g/kW-hr	1.7	0.7	0.1	0.003	NA
lb/10^6 scf[g]	300	120	23	0.6	NA
kg/10^6 $\underline{N}m^3$[g]	4,700	1,940	280	9.2	NA

[a] All factors based on References 2 and 3.

[b] These factors are for compressor engines operated at rated load. In general, NO_x emissions will increase with increasing load and intake (manifold) air temperature and decrease with increasing air-fuel ratios (excess air rates) and absolute humidity. Quantitative estimates of the effects of these variables are presented in Reference 2.

[c] These factors represent total hydrocarbons. Nonmethane hydrocarbons are estimated to make up to 5 to 10 percent of these totals, on the average.

[d] Based on an assumed sulfur content of pipeline gas of 2000 gr/10^6 scf (4600 g/$\underline{N}m^3$). If pipeline quality natural gas is not fired, a material balance should be performed to determine SO_2 emissions based on the actual sulfur content.

[e] Not available from existing data.

[f] These factors are calculated from the above factors for reciprocating engines assuming a heating value of 1050 Btu/scf (9350 kcal/$\underline{N}m^3$) for natural gas and an average fuel consumption of 7500 Btu/hp-hr (2530 kcal/kW-hr).

[g] These factors are calculated from the above factors for gas turbines assuming a heating value of 1,050 Btu/scf (9,350 kcal/$\underline{N}m^3$) of natural gas and an average fuel consumption of 10,000 Btu/hp-hr (3,380 kcal/kW-hr).

References for Section 3.3.2

1. Standard Support Document and Environmental Impact Statement - Stationary Reciprocating Internal Combustion Engines. Aerotherm/Acurex Corp., Mountain View, Calif. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. 68-02-1318, Task Order No. 7, November 1974.

2. Urban, C.M. and K.J. Springer. Study of Exhaust Emissions from Natural Gas Pipeline Compressor Engines. Southwest Research Institute, San Antonio, Texas. Prepared for American Gas Association, Arlington, Va. February 1975.

3. Dietzmann, H.E. and K.J. Springer. Exhaust Emissions from Piston and Gas Turbine Engines Used in Natural Gas Transmission. Southwest Research Institute, San Antonio, Texas. Prepared for American Gas Association, Arlington, Va. January 1974.

3.3.3 Gasoline and Diesel Industrial Engines

by David S. Kircher

3.3.3-1 General – This engine category covers a wide variety of industrial applications of both gasoline and diesel internal combustion power plants, such as fork lift trucks, mobile refrigeration units, generators, pumps, and portable well-drilling equipment. The rated power of these engines covers a rather substantial range–from less than 15 kW to 186 kW (20 to 250 hp) for gasoline engines and from 34 kW to 447 kW (45 to 600 hp) for diesel engines. Understandably, substantial differences in both annual usage (hours per year) and engine duty cycles also exist. It was necessary, therefore, to make reasonable assumptions concerning usage in order to formulate emission factors.[1]

3.3.3-2 Emissions – Once reasonable usage and duty cycles for this category were ascertained, emission values from each of the test engines [1] were aggregated (on the basis of nationwide engine population statistics) to arrive at the factors presented in Table 3.3.3-1. Because of their aggregate nature, data contained in this table must be applied to a population of industrial engines rather than to an individual power plant.

The best method for calculating emissions is on the basis of "brake specific" emission factors (g/kWh or lb/hphr). Emissions are calculated by taking the product of the brake specific emission factor, the usage in hours (that is, hours per year or hours per day), the power available (rated power), and the load factor (the power actually used divided by the power available).

Table 3.3.3-1. EMISSION FACTORS FOR GASOLINE- AND DIESEL-POWERED INDUSTRIAL EQUIPMENT
EMISSION FACTOR RATING: C

Pollutant[a]	Engine category[b]	
	Gasoline	Diesel
Carbon monoxide		
g/hr	5700.	197.
lb/hr	12.6	0.434
g/kWh	267.	4.06
g/hphr	199.	3.03
kg/10^3 liter	472.	12.2
lb/10^3 gal	3940.	102.
Exhaust hydrocarbons		
g/hr	191.	72.8
lb/hr	0.421	0.160
g/kWh	8.95	1.50
g/hphr	6.68	1.12
kg/10^3 liter	15.8	4.49
lb/10^3 gal	132.	37.5
Evaporative hydrocarbons		
g/hr	62.0	–
lb/hr	0.137	–
Crankcase hydrocarbons		
g/hr	38.3	–
lb/hr	0.084	–

Table 3.3.3-1. (continued). EMISSION FACTORS FOR GASOLINE- AND DIESEL-POWERED INDUSTRIAL EQUIPMENT
EMISSION FACTOR RATING: C

Pollutant[a]	Engine category[b]	
	Gasoline	Diesel
Nitrogen oxides		
g/hr	148.	910.
lb/hr	0.326	2.01
g/kWh	6.92	18.8
g/hphr	5.16	14.0
kg/10^3 liter	12.2	56.2
lb/10^3 gal	102.	469.
Aldehydes		
g/hr	6.33	13.7
lb/hr	0.014	0.030
g/kWh	0.30	0.28
g/hphr	0.22	0.21
kg/10^3 liter	0.522	0.84
lb/10^3 gal	4.36	7.04
Sulfur oxides		
g/hr	7.67	60.5
lb/hr	0.017	0.133
g/kWh	0.359	1.25
g/hphr	0.268	0.931
kg/10^3 liter	0.636	3.74
lb/10^3 gal	5.31	31.2
Particulate		
g/hr	9.33	65.0
lb/hr	0.021	0.143
g/kWh	0.439	1.34
g/hphr	0.327	1.00
kg/10^3 liter	0.775	4.01
lb/10^3 gal	6.47	33.5

[a] References 1 and 2.

[b] As discussed in the text, the engines used to determine the results in this table cover a wide range of uses and power. The listed values do not, however, necessarily apply to some very large stationary diesel engines.

References for Section 3.3.3

1. Hare, C. T. and K. J. Springer. Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines. Final Report. Part 5: Heavy-Duty Farm, Construction, and Industrial Engines. Southwest Research Institute. San Antonio, Texas. Prepared for Environmental Protection Agency, Research Triangle Park, N.C., under Contract No. EHS 70-108. October 1973. 105 p.
2. Hare, C. T. Letter to C. C. Masser of the Environmental Protection Agency concerning fuel-based emission rates for farm, construction, and industrial engines. San Antonio, Tex. January 14, 1974.

4. EVAPORATION LOSS SOURCES

Evaporation losses include the organic solvents emitted from dry-cleaning plants and surface-coating operations as well as the volatile matter in petroleum products. This chapter presents the hydrocarbon emissions from these sources, including liquid petroleum storage and marketing. Where possible, the effect of controls to reduce the emissions of organic compounds has been shown.

4.1 DRY CLEANING

by Susan Sercer

4.1.1 General[1,2]

Dry cleaning involves the cleaning of fabrics with non-aqueous organic solvents. The dry cleaning process requires three steps: (1) washing the fabric in solvent, (2) spinning to extract excess solvent, and (3) drying by tumbling in a hot airstream.

Two general types of cleaning fluids are used in the industry: petroleum solvents and synthetic solvents. Petroleum solvents, such as Stoddard or 140-F, are inexpensive, combustible hydrocarbon mixtures similar to kerosene. Operations using petroleum solvents are known as petroleum plants. Synthetic solvents are nonflammable but more expensive halogenated hydrocarbons. Perchloroethylene and trichlorotrifluoroethane are the two synthetic dry cleaning solvents presently in use. Operations using these synthetic solvents are called "perc" plants and fluorocarbon plants, respectively.

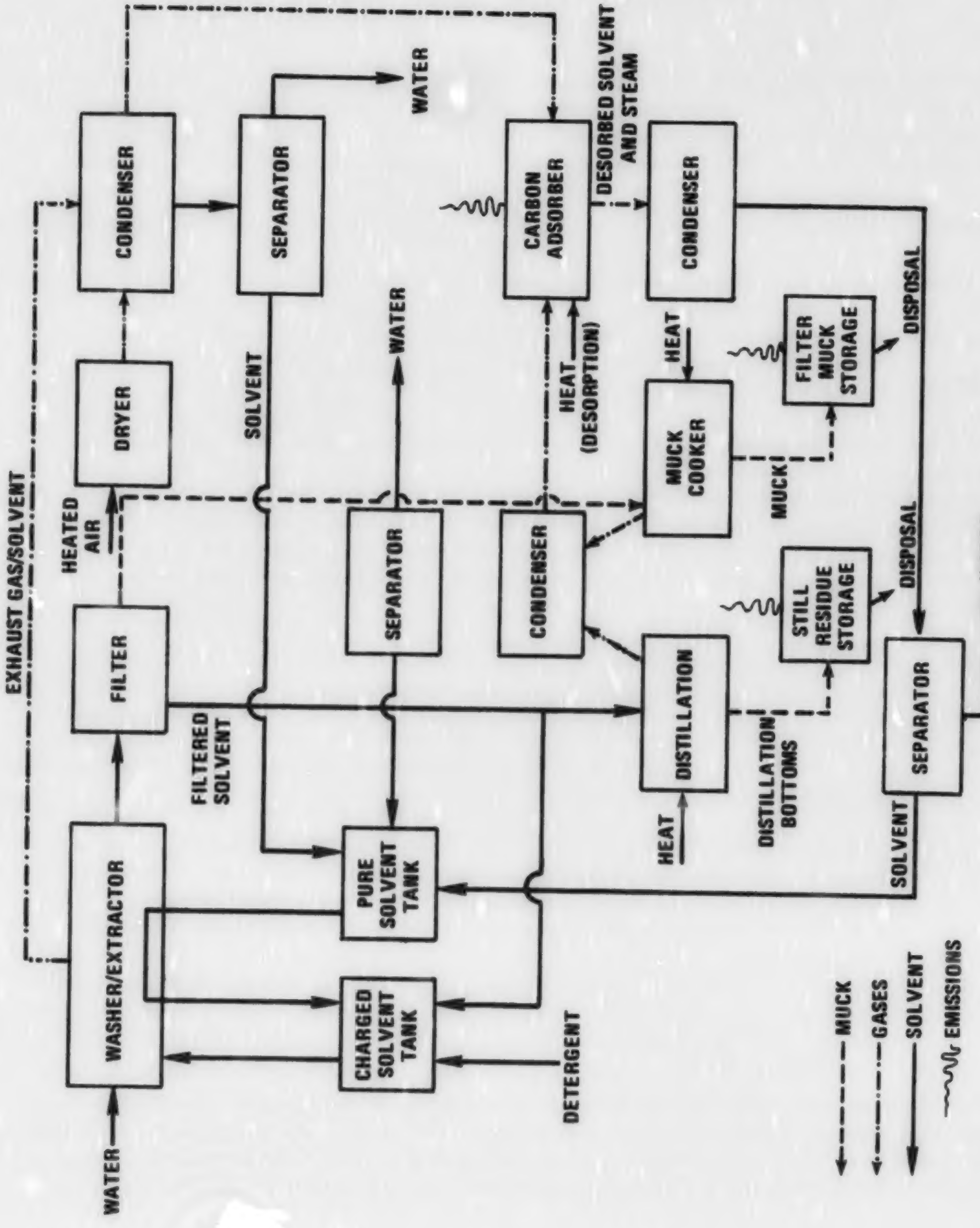
There are two basic types of dry cleaning machines: transfer and dry-to-dry. Transfer machines accomplish washing and drying in separate machines. Usually the washer extracts excess solvent from the clothes before they are transferred to the dryer, however, some older petroleum plants have separate extractors for this purpose. Dry-to-dry machines are single units that perform all of the washing, extraction, and drying operations. All petroleum solvent machines are the transfer type, but synthetic solvent plants can be either type.

The dry cleaning industry can be divided into three sectors: coin-operated facilities, commercial operations, and industrial cleaners. Coin-operated facilities are usually part of a laundry and supply "self-service" type dry cleaning for consumers. Only synthetic solvents are used in coin-operated dry cleaning machines. Such machines are small, with a capacity of 8 to 25 lb (3.6 to 11.5 kg) of clothing.

Commercial operations, such as small neighborhood or franchise dry cleaning shops, clean soiled apparel for the consumer. Generally, perchloroethylene and petroleum solvents are used in commercial operations. A typical "perc" plant operates a 30 to 60 lb (14 to 27 kg) capacity washer/extractor and an equivalent size reclaiming dryer.

Industrial cleaners are larger dry cleaning plants which supply rental service of uniforms, mats, mops, etc., to businesses or industries. Although petroleum solvents are used extensively, perchloroethylene is used by approximately 50% of the industrial dry cleaning establishments. A typical large industrial cleaner has a 500 lb (230 kg) capacity washer/extractor and three to six 100 lb (38 kg) capacity dryers.

A typical perc plant is shown in Figure 4.1-1. Although one solvent tank may be used, the typical perc plant uses two tanks for washing. One tank contains pure solvent; the other tank contains "charged" solvent—used solvent to which small amounts of detergent have been added to aid in cleaning. Generally, clothes are cleaned in charged solvent and rinsed in pure solvent. A water bath may also be used.



WATER
WASHER/EXTRACTOR
CHARGED SOLVENT TANK
DETERGENT
PURE SOLVENT TANK
EXHAUST GAS/SOLVENT
FILTER
FILTERED SOLVENT
HEATED AIR
DRYER
CONDENSER
SEPARATOR
WATER
SOLVENT
SEPARATOR
WATER
CONDENSER
CARBON ADSORBER
HEAT (DESORPTION)
DESORBED SOLVENT AND STEAM
CONDENSER
HEAT
MUCK COOKER
MUCK
FILTER MUCK STORAGE
DISPOSAL
DISTILLATION
HEAT
DISTILLATION BOTTOMS
STILL RESIDUE STORAGE
DISPOSAL
SEPARATOR
SOLVENT
WATER
MUCK
GASES
SOLVENT
EMISSIONS

Figure 4.1-1. Perchloroethylene dry cleaning plant flow diagram.

After the clothes have been washed, the used solvent is filtered, and part of the filtered solvent is returned to the charged solvent tank for washing the next load. The remaining solvent is then distilled to remove oils, fats, greases, etc., and returned to the pure solvent tank. The resulting distillation bottoms are typically stored on the premises until disposed of. The filter cake and collected solids (muck) are usually removed from the filter once a day. Before disposal, the muck may be "cooked" to recover additional solvent. Still and muck cooker vapors are vented to a condenser and separator where more solvent is reclaimed. In many perc plants, the condenser off-gases are vented to a carbon adsorption unit for additional solvent recovery.

After washing, the clothes are transferred to the dryer where they are tumbled in a heated airstream. Exhaust gases from the dryer, along with a small amount of exhaust gases from the washer/extractor, are vented to a water-cooled condenser and water separator. Recovered solvent is returned to the pure solvent storage tank. In 30-50 percent of the perc plants, the condenser off-gases are vented to a carbon adsorption unit for additional solvent recovery. To reclaim this solvent, the unit must be periodically desorbed with steam—typically at the end of each day. Desorbed solvent and water are condensed and separated; recovered solvent is returned to the pure solvent tank.

A petroleum plant would differ from Figure 4.1-1 chiefly in that there would be no recovery of solvent from the washer and dryer and no muck cooker. A fluorocarbon plant would differ in that a nonvented refrigeration system would be used in place of a carbon adsorption unit. Another difference would be that a typical fluorocarbon plant would use a cartridge filter which is drained and disposed of after several hundred cycles.

Emissions and Controls[1,2,3]

The solvent material itself is the primary emission of concern from dry cleaning operations. Solvent is given off by the washer, dryer, solvent still, muck cooker, still residue and filter muck storage areas, as well as leaky pipes, flanges, and pumps.

Petroleum plants have generally not employed solvent recovery because of the low cost of petroleum solvents and the fire hazards associated with collecting vapors. Some emission control, however, can be obtained by maintaining all equipment in good condition (e.g., preventing lint accumulation, preventing solvent leakage, etc.) and by using good operating practices (e.g., not overloading machinery). Both carbon adsorption and incineration appear to be technically feasible controls for petroleum plants, but costs are high.

Solvent recovery is necessary in perc plants due to the higher cost of perchloroethylene. As shown in Figure 4.1-1, recovery is effected on the washer, dryer, still, and muck cooker through the use of condensers, water/solvent separators, and carbon adsorption units. Periodically (typically once a day), solvent collected in the carbon adsorption unit is desorbed with steam, condensed, separated from the condensed water, and returned to the pure solvent storage tank. Residual solvent emitted from treated distillation bottoms and muck is not recovered. As in petroleum plants, good emission control can be obtained by good housekeeping practices (maintaining all equipment in good condition and using good operating practices).

All fluorocarbon machines are of the dry-to-dry variety to conserve solvent vapor, and all are closed systems with built-in solvent recovery. High emissions can occur, however, as a result of poor maintenance and operation of equipment. Refrigeration systems are installed on newer machines to recover solvent from the washer/dryer exhaust gases.

Emission factors for dry cleaning operations are presented in Table 4.1-1.

Table 4.1-1. SOLVENT LOSS EMISSION FACTORS FOR DRY CLEANING OPERATIONS
EMISSION FACTOR RATING: B

Solvent type (Process used)	Source	Emission rate[a]	
		Typical systems	Well-controlled system
		lb/100 lb (kg/100 kg)	lb/100 lb (kg/100 kg)
Petroleum (transfer process)	washer/dryer[f]	18	2[b]
	filter disposal		
	uncooked (drained)	5	
	centrifuged		0.5 - 1
	still residue disposal	2	0.5 - 1
	miscellaneous[c]	3	1
Perchloroethylene (transfer process)	washer/dryer/still/muck cooker	8[d]	0.3[b]
	filter disposal		
	uncooked muck	14	
	cooked muck	1.3	0.5 - 1.3
	cartridge filter	1.1	0.5 - 1.1
	still residue disposal	1.6	0.5 - 1.6
	miscellaneous[c]	1.5	1
Trichlorotrifluoroethane (dry-to-dry process)	washer/dryer/still[e]	0	0
	cartridge filter disposal	1	1
	still residue disposal	0.5	0.5
	miscellaneous[c]	1 - 3	1 - 3

[a] Units are in terms of weight of solvent per weight of clothes cleaned (capacity x loads). Emissions may be estimated on an alternative basis by determining the amount of solvent consumed. Assuming that all solvent input to dry cleaning operations is eventually evaporated to the atmosphere, an emission factor of 2000 lb/ton of solvent consumed can be applied. All emission factors are based on References 1, 2 and 3.

[b] Emissions from the washer, dryer, still, and muck cooker are collectively passed through a carbon adsorber.

[c] Miscellaneous sources include fugitive emissions from flanges, pumps, pipes, storage tanks, fixed losses (for example, opening and closing the dryer), etc.

[d] Uncontrolled emissions from the washer, dryer, still, and muck cooker average about 8 lb/100 lb (8 kg/100 kg). Roughly 15% of the solvent emitted comes from the washer, 75% from the dryer, and 5% from both the still and the muck cooker.

[e] Emission factors are based on the typical refrigeration system installed in fluorocarbon plants.

[f] Different materials in the wash retain varying amounts of solvent (synthetic: 10 kg/100 kg, cotton: 20 kg/100 kg, leather: 40 kg/100 kg).

References for Section 4.1

1. Study to Support New Source Performance Standards for the Dry Cleaning Industry, EPA Contract 68-02-1412, Task Order No. 4, prepared by TRW Inc., Vienna, Virginia, May 7, 1976. Kleeberg, Charles, EPA, Office of Air Quality Planning and Standards.

2. Standard Support and Environmental Impact Statement for the Dry Cleaning Industry. Durham, North Carolina. June 28, 1976.

3. Control of Volatile Organic Emissions from Dry Cleaning Operations (Draft Document), Durham, North Carolina. April 15, 1977.

4.2 SURFACE COATING

4.2.1 Process Description[1,2]

Surface-coating operations primarily involve the application of paint, varnish, lacquer, or paint primer for decorative or protective purposes. This is accomplished by brushing, rolling, spraying, flow coating, and dipping. Some of the industries involved in surface-coating operations are automobile assemblies, aircraft companies, container manufacturers, furniture manufacturers, appliance manufacturers, job enamelers, automobile repainters, and plastic products manufacturers.

4.2.2 Emissions and Controls[3]

Emissions of hydrocarbons occur in surface-coating operations because of the evaporation of the paint vehicles, thinners, and solvents used to facilitate the application of the coatings. The major factor affecting these emissions is the amount of volatile matter contained in the coating. The volatile portion of most common surface coatings averages approximately 50 percent, and most, if not all, of this is emitted during the application and drying of the coating. The compounds released include aliphatic and aromatic hydrocarbons, alcohols, ketones, esters, alkyl and aryl hydrocarbon solvents, and mineral spirits. Table 4.2-1 presents emission factors for surface-coating operations.

Control of the gaseous emissions can be accomplished by the use of adsorbers (activated carbon) or afterburners. The collection efficiency of activated carbon has been reported at 90 percent or greater. Water curtains or filler pads have little or no effect on escaping solvent vapors; they are widely used, however, to stop paint particulate emissions.

Table 4.2-1. GASEOUS HYDROCARBON EMISSION FACTORS FOR SURFACE-COATING APPLICATIONS[a]
EMISSION FACTOR RATING: B

Type of coating	Emissions[b]	
	lb/ton	kg/MT
Paint	1120	560
Varnish and shellac	1000	500
Lacquer	1540	770
Enamel	840	420
Primer (zinc chromate)	1320	660

[a] Reference 1.

[b] Reported as undefined hydrocarbons, usually organic solvents, both aryl and alkyl. Paints weigh 10 to 15 pounds per gallon (1.2 to 1.9 kilograms per liter); varnishes weigh about 7 pounds per gallon (0.84 kilogram per liter).

References for Section 4.2

1. Weiss, S.F. Surface Coating Operations. In: Air Pollution Engineering Manual, Danielson, J.A. (ed.). U.S. DHEW, PHS, National Center for Air Pollution Control. Cincinnati, Ohio. Publication Number 999-AP-40. p.387-390.

2. Control Techniques for Hydrocarbon and Organic Gases From Stationary Sources. U.S. DHEW, PHS, EHS, National Air Pollution Control Administration. Washington, D.C. Publication Number AP-68. October 1969. Chapter 7.6.

3. Air Pollutant Emission Factors. Final Report. Resources Research, Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.

4.3 STORAGE OF PETROLEUM LIQUIDS[1]

by Charles C. Masser

Fundamentally, the petroleum industry consists of three operations: (1) petroleum production and transportation, (2) petroleum refining, and (3) transportation and marketing of finished petroleum products. All three operations require some type of storage for petroleum liquids. Storage tanks for both crude and finished products can be sources of evaporative emissions. Figure 4.3-1 presents a schematic of the petroleum industry and its points of emissions from storage operations.

4.3.1 Process Description

Four basic tank designs are used for petroleum storage vessels: fixed roof, floating roof (open type and covered type), variable vapor space, and pressure (low and high).

4.3.1.1 **Fixed Roof Tanks[2]** - The minimum accepted standard for storage of volatile liquids is the fixed roof tank (Figure 4.3-2). It is usually the least expensive tank design to construct. Fixed roof tanks basically consist of a cylindrical steel shell topped by a coned roof having a minimum slope of 3/4 inch in 12 inches. Fixed roof tanks are generally equipped with a pressure/vacuum vent designed to contain minor vapor volume changes. For large fixed roof tanks, the recommended maximum operating pressure/vacuum is +0.03 psig/-0.03 psig (+2.1 g/cm^2/-2.1 g/cm^2).

4.3.1.2 **Floating Roof Tanks[3]** - Floating roof tanks reduce evaporative storage losses by minimizing vapor spaces. The tank consists of a welded or riveted cylindrical steel wall, equipped with a deck or roof which is free to float on the surface of the stored liquid. The roof then rises and falls according to the depth of stored liquid. To ensure that the liquid surface is completely covered, the roof is equipped with a sliding seal which fits against the tank wall. Sliding seals are also provided at support columns and at all other points where tank appurtenances pass through the floating roof.

Until recent years, the most commonly used floating roof tank was the conventional open-type tank. The open-type floating roof tank exposes the roof deck to the weather; provisions must be made for rain water drainage, snow removal, and sliding seal dirt protection. Floating roof decks are of three general types: pan, pontoon, and double deck. The pan-type roof consists of a flat metal plate with a vertical rim and sufficient stiffening braces to maintain rigidity (Figure 4.3-3). The single metal plate roof in contact with the liquid readily conducts solar heat, resulting in higher vaporization losses than other floating roof decks. The roof is equipped with automatic vents for pressure and vacuum release. The pontoon roof is a pan-type floating roof with pontoon sections added to the top of the deck around the rim. The pontoons are arranged to provide floating stability under heavy loads of water and snow. Evaporation losses due to solar heating are about the same as for pan-type roofs. Pressure/vacuum vents are required on pontoon roof tanks. The double deck roof is similar to a pan-type floating roof, but consists of a hollow double deck covering the entire surface of the roof (Figure 4.3-4). The double deck adds rigidity, and the dead air space between the upper and lower deck provides significant insulation from solar heating. Pressure/vacuum vents are also required.

The covered-type floating roof tank is essentially a fixed-roof tank with a floating roof deck inside the tank (Figure 4.3-5). The American Petroleum Institute has designated the term "covered floating" roof to describe a fixed roof tank with an internal steel pan-type floating roof. The term "internal floating cover" has been chosen by the API to describe internal covers constructed of materials other than steel. Floating roofs and covers can be installed inside existing fixed roof tanks. The fixed roof protects the floating roof from the weather, and no provision is necessary for rain or snow removal, or for seal

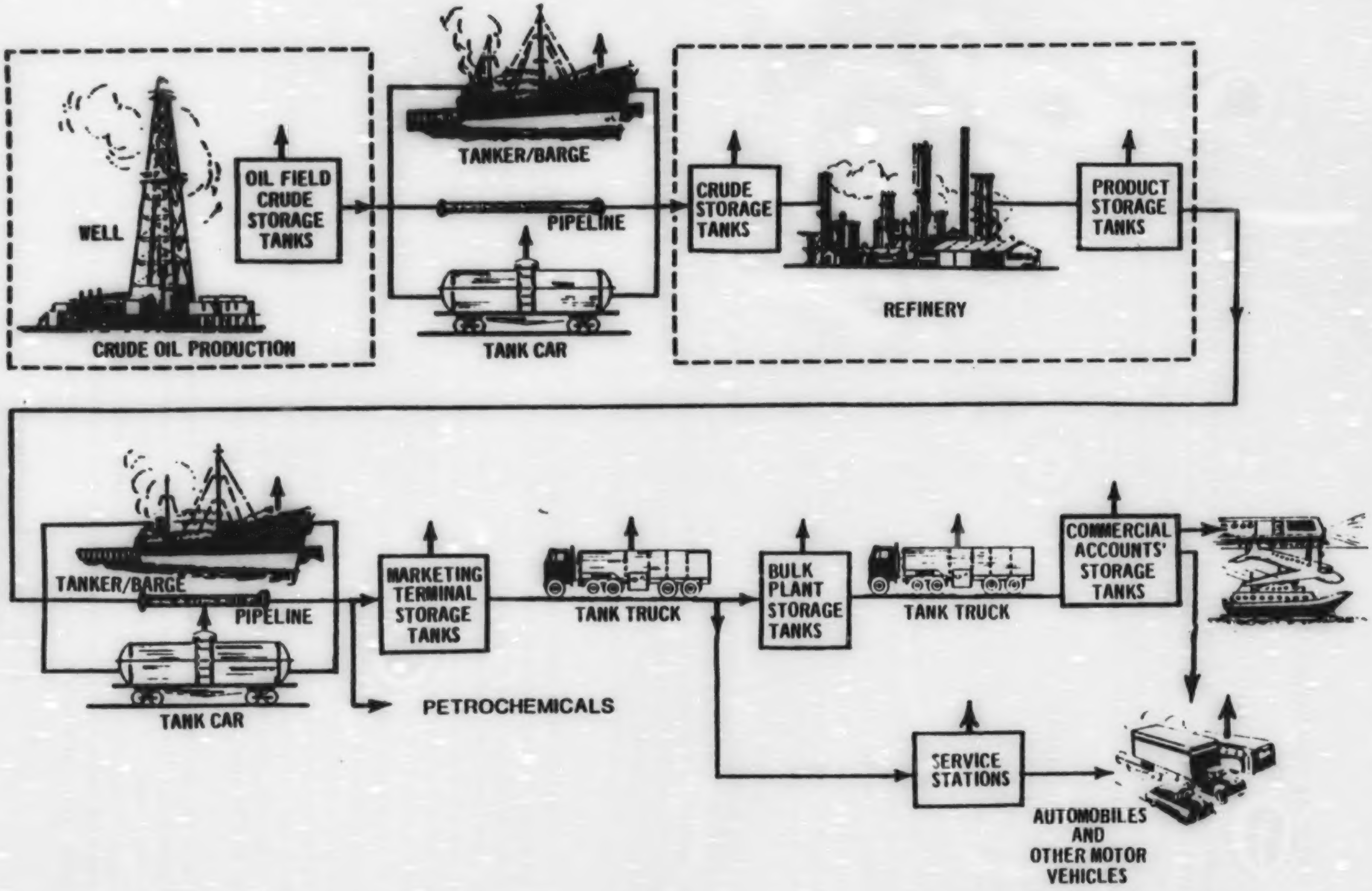

WELL
OIL FIELD CRUDE STORAGE TANKS
CRUDE OIL PRODUCTION
TANKER/BARGE
PIPELINE
TANK CAR
CRUDE STORAGE TANKS
PRODUCT STORAGE TANKS
REFINERY
TANKER/BARGE
PIPELINE
TANK CAR
MARKETING TERMINAL STORAGE TANKS
PETROCHEMICALS
TANK TRUCK
BULK PLANT STORAGE TANKS
TANK TRUCK
COMMERCIAL ACCOUNTS' STORAGE TANKS
SERVICE STATIONS
AUTOMOBILES AND OTHER MOTOR VEHICLES

Figure 4.3-1. Flowsheet of petroleum production, refining, and distribution systems. (Sources of organic evaporative emissions are indicated by vertical arrows.)

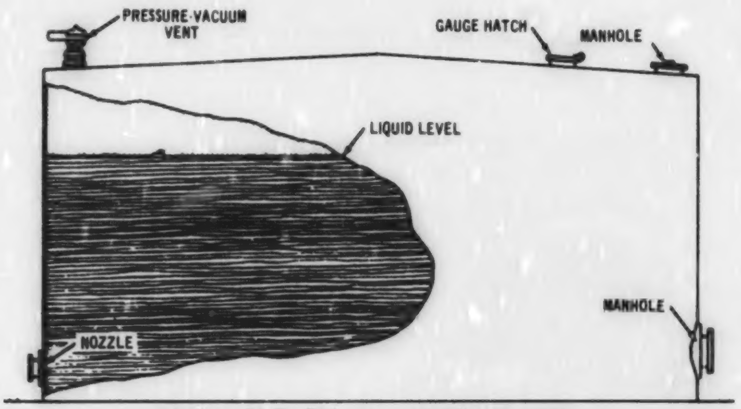

PRESSURE-VACUUM VENT
GAUGE HATCH
MANHOLE
LIQUID LEVEL
MANHOLE
NOZZLE

Figure 4.3-2. Fixed roof storage tank.

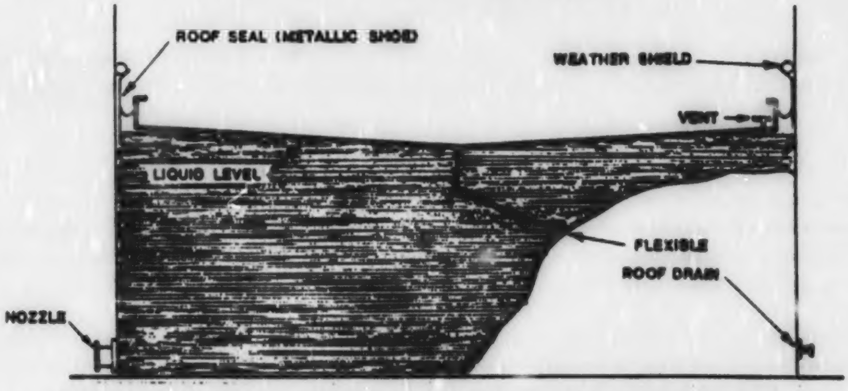

ROOF SEAL (METALLIC SHOE)
WEATHER SHIELD
VENT
LIQUID LEVEL
FLEXIBLE
ROOF DRAIN
NOZZLE

Figure 4.3-3. Pan-type floating roof storage tank (metallic seals).

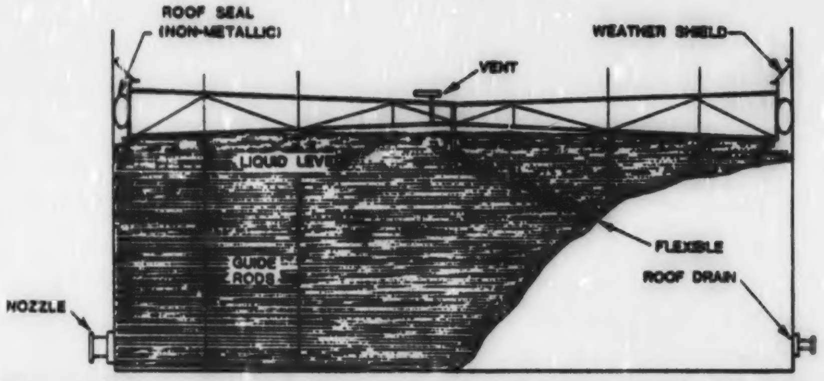

ROOF SEAL
(NON-METALLIC)
WEATHER SHIELD
VENT
LIQUID LEVEL
GUIDE RODS
FLEXIBLE
ROOF DRAIN
NOZZLE

Figure 4.3-4. Double deck floating roof storage tank (non-metallic seals).

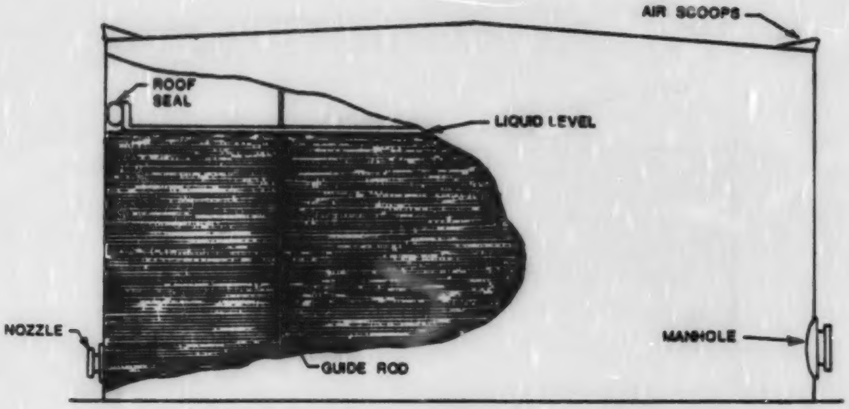

AIR SCOOPS
ROOF SEAL
LIQUID LEVEL
NOZZLE
MANHOLE
GUIDE ROD

Figure 4.3-5. Covered floating roof storage tank.

protection. Antirotational guides must be provided to maintain roof alignment, and the space between the fixed and floating roofs must be vented to prevent the possible formation of a flammable mixture.

4.3.1.3 Variable Vapor Space Tanks[4] - Variable vapor space tanks are equipped with expandable vapor reservoirs to accommodate vapor volume fluctuations attributable to temperature and barometric pressure changes. Although variable vapor space tanks are sometimes used independently, they are normally connected to the vapor spaces of one or more fixed roof tanks. The two most common types of variable vapor space tanks are lifter roof tanks and flexible diaphragm tanks.

Lifter roof tanks have a telescoping roof that fits loosely around the outside of the main tank wall. The space between the roof and the wall is closed by either a wet seal, which consists of a trough filled with liquid, or a dry seal, which employs a flexible coated fabric in place of the trough (Figure 4.3-6).

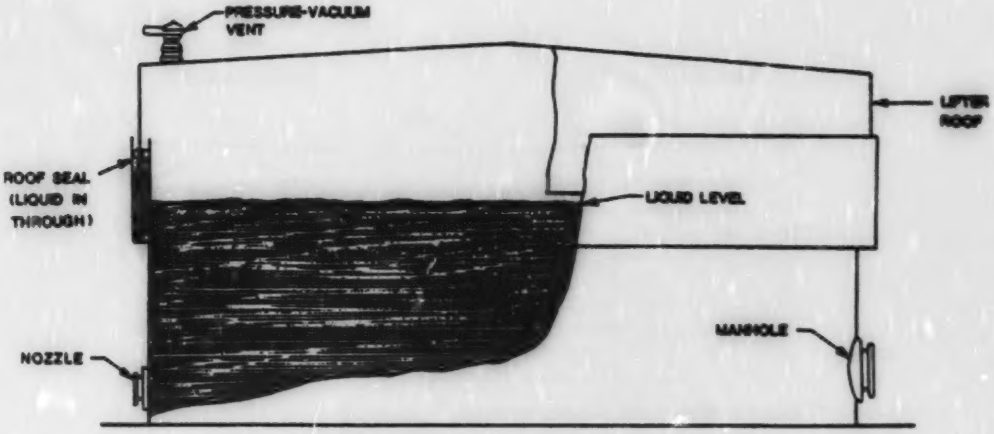

PRESSURE-VACUUM VENT
LIFTER ROOF
ROOF SEAL (LIQUID IN THROUGH)
LIQUID LEVEL
MANHOLE
NOZZLE

Figure 4.3-6. Lifter roof storage tank (wet seal).

Flexible diaphragm tanks utilize flexible membranes to provide the expandable volume. They may be separate gasholder type units, or integral units mounted atop fixed roof tanks (Figure 4.3-7).

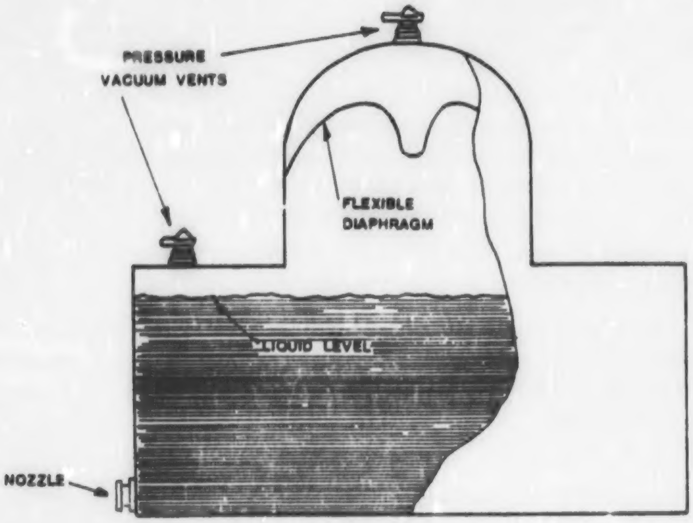


Figure 4.3-7. Flexible diaphragm tank (integral unit).

4.3.1.4 **Pressure Tanks**[5] - Pressure tanks are designed to withstand relatively large pressure variations without incurring a loss. They are generally used for storage of high volatility stocks, and they are constructed in many sizes and shapes, depending on the operating range. The noded spheroid and noded hemispheroid shapes are generally used as low-pressure tanks (17 to 30 psia or 12 to 21 mg/m²), while the horizontal cylinder and spheroid shapes are generally used as high-pressure tanks (up to 265 psia or 186 mg/m²).

4.3.2 Emissions and Controls

There are six sources of emissions from petroleum liquids in storage: fixed roof breathing losses, fixed roof working losses, floating roof standing storage losses, floating roof withdrawal losses, variable vapor space filling losses, and pressure tank losses.[6]

Fixed roof breathing losses consist of vapor expelled from a tank because of the thermal expansion of existing vapors, vapor expansion caused by barometric pressure changes, and/or an increase in the amount of vapor due to added vaporization in the absence of a liquid-level change.

Fixed roof working losses consist of vapor expelled from a tank as a result of filling and emptying operations. Filling loss is the result of vapor displacement by the input of liquid. Emptying loss is the expulsion of vapors subsequent to product withdrawal, and is attributable to vapor growth as the newly inhaled air is saturated with hydrocarbons.

Floating roof standing storage losses result from causes other than breathing or changes in liquid level. The largest potential source of this loss is attributable to an improper fit of the seal and shoe to the shell, which exposes some liquid surface to the atmosphere. A small amount of vapor may escape between the flexible membrane seal and the roof.

Floating roof withdrawal losses result from evaporation of stock which wets the tank wall as the roof descends during emptying operations. This loss is small in comparison to other types of losses.

Variable vapor space filling losses result when vapor is displaced by the liquid input during filling operations. Since the variable vapor space tank has an expandable vapor storage capacity, this loss is not as large as the filling loss associated with fixed roof tanks. Loss of vapor occurs only when the vapor storage capacity of the tank is exceeded.

Pressure tank losses occur when the pressure inside the tank exceeds the design pressure of the tank, which results in relief vent opening. This happens only when the tank is filled improperly, or when abnormal vapor expansion occurs. These are not regularly occurring events, and pressure tanks are not a significant source of loss under normal operating conditions.

The total amount of evaporation loss from storage tanks depends upon the rate of loss and the period of time involved. Factors affecting the rate of loss include:

1. True vapor pressure of the liquid stored.
2. Temperature changes in the tank.
3. Height of the vapor space (tank outage).
4. Tank diameter.
5. Schedule of tank filling and emptying.
6. Mechanical condition of tank and seals.
7. Type of tank and type of paint applied to outer surface.

The American Petroleum Institute has developed empirical formulae, based on field testing, that correlate evaporative losses with the above factors and other specific storage factors.

4.3.2.1 Fixed Roof Tanks[2,7] - Fixed roof breathing losses can be estimated from:

$$L_B = 2.21 \times 10^{-4} M \left[\frac{P}{14.7 - P}\right]^{0.68} D^{1.73} H^{0.51} \Delta T^{0.50} F_p C K_c \qquad (1)$$

where: L_B = Fixed roof breathing loss (lb/day).

M = Molecular weight of vapor in storage tank (lb/lb mole). (see Table 4.3-1).

P = True vapor pressure at bulk liquid conditions (psia); see Figures 4.3-8, 4.3-9, or Table 4.3-1.

D = Tank diameter (ft).

H = Average vapor space height, including roof volume correction (ft); see note (1).

ΔT = Average ambient temperature change from day to night (°F).

F_p = Paint factor (dimensionless); see Table 4.3-2.

C = Adjustment factor for small diameter tanks (dimensionless); see Figure 4.3-10.

K_c = Crude oil factor (dimensionless); see note (2).

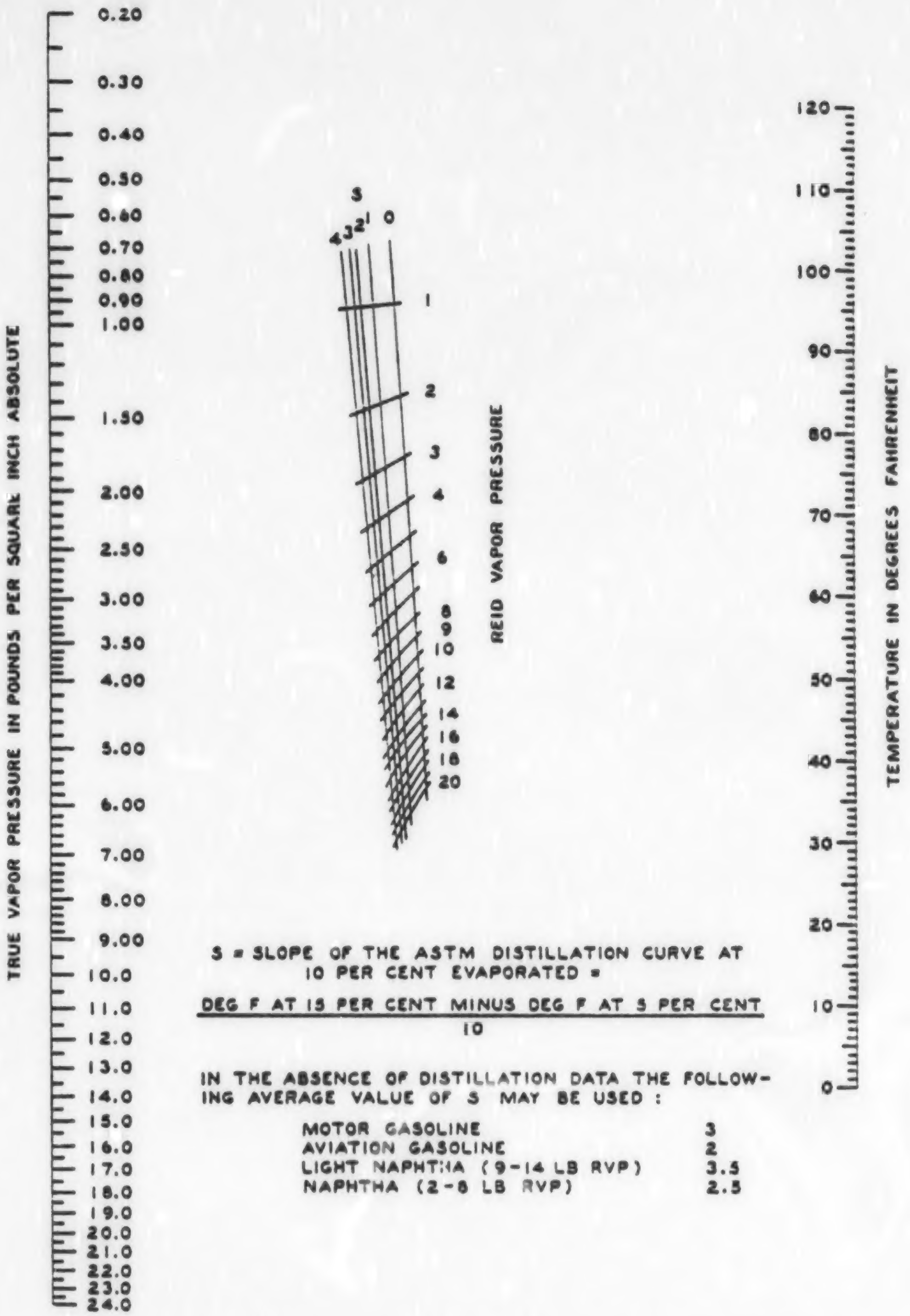
Note: (1) The vapor space in a cone roof is equivalent in volume to a cylinder which has the same base diameter as the cone and is one-third the height of the cone.

(2) $K_c = (0.65)$ for crude oil, $K_c = (1.0)$ for gasoline and all other liquids.

API reports that calculated breathing loss from Equation (1) may deviate in the order of ± 10 percent from actual breathing loss.

Table 4.3-1. PHYSICAL PROPERTIES OF HYDROCARBONS 7,9

Hydrocarbon	Vapor molecular weight @ 60°F	Product density (d), lb/gal @ 60°F	Condensed vapor density (w), lb/gal @ 60°F	Vapor pressure in psia at:						
				40°F	50°F	60°F	70°F	80°F	90°F	100°F
Fuels										
Gasoline RVP 13	62	5.6	4.9	4.7	5.7	6.9	8.3	9.9	11.7	13.8
Gasoline RVP 10	66	5.6	5.1	3.4	4.2	5.2	6.2	7.4	8.8	10.5
Gasoline RVP 7	68	5.6	5.2	2.3	2.9	3.5	4.3	5.2	6.2	7.4
Crude oil RVP 5	50	7.1	4.5	1.8	2.3	2.8	3.4	4.0	4.8	5.7
Jet naphtha (JP-4)	80	6.4	5.4	0.8	1.0	1.3	1.6	1.9	2.4	2.7
Jet kerosene	130	7.0	6.1	0.0041	0.0060	0.0085	0.011	0.015	0.021	0.029
Distillate fuel No. 2	130	7.1	6.1	0.0031	0.0045	0.0074	0.0090	0.012	0.016	0.022
Residual oil No. 6	190	7.9	6.4	0.00002	0.00003	0.00004	0.00006	0.00009	0.00013	0.00019
Petrochemicals										
Acetone	58	6.6	6.6	1.7	2.2	2.9	3.7	4.7	5.9	7.3
Acrylonitrile	53	6.8	6.8	0.8	1.0	1.4	1.8	2.4	3.1	4.0
Benzene	78	7.4	7.4	0.6	0.9	1.2	1.5	2.0	2.6	3.3
Carbon disulfide	76	10.6	10.6	3.0	3.9	4.8	6.0	7.4	9.2	11.2
Carbon tetrachloride	154	13.4	13.4	0.8	1.1	1.4	1.8	2.3	3.0	3.8
Chloroform	119	12.5	12.5	1.5	1.9	2.5	3.2	4.1	5.2	6.3
Cyclohexane	84	6.5	6.5	0.7	0.9	1.2	1.6	2.1	2.6	3.2
1, 2 - Dichlorethane	99	10.5	10.5	0.6	0.8	1.0	1.4	1.7	2.2	2.8
Ethylacetate	88	7.6	7.6	0.6	0.8	1.1	1.5	1.9	2.5	3.2
Ethyl alcohol	46	6.6	6.6	0.2	0.4	0.6	0.9	1.2	1.7	2.3
Isopropyl alcohol	60	6.6	6.6	0.2	0.3	0.5	0.7	0.9	1.3	1.8
Methyl alcohol	32	6.6	6.6	0.7	1.0	1.4	2.0	2.6	3.5	4.5
Methylene chloride	85	11.1	11.1	3.1	4.3	5.4	6.8	8.7	10.3	13.3
Methyl-ethyl ketone	72	6.7	6.7	0.7	0.9	1.2	1.5	2.1	2.7	3.3
Methyl-methacrylate	100	7.9	7.9	0.1	0.2	0.3	0.5	0.8	1.1	1.4
1, 1, 1 - Trichloroethane	133	11.2	11.2	0.9	1.2	1.6	2.0	2.6	3.3	4.2
Trichloroethylene	131	12.3	12.3	0.5	0.7	0.9	1.2	1.5	2.0	2.6
Toluene	92	7.3	7.3	0.2	0.2	0.3	0.4	0.6	0.8	1.0
Vinylacetate	86	7.8	7.8	0.7	1.0	1.3	1.7	2.3	3.1	4.0



S = SLOPE OF THE ASTM DISTILLATION CURVE AT 10 PER CENT EVAPORATED =

$$\frac{\text{DEG F AT 15 PER CENT MINUS DEG F AT 5 PER CENT}}{10}$$

IN THE ABSENCE OF DISTILLATION DATA THE FOLLOWING AVERAGE VALUE OF S MAY BE USED :

MOTOR GASOLINE	3
AVIATION GASOLINE	2
LIGHT NAPHTHA (9-14 LB RVP)	3.5
NAPHTHA (2-8 LB RVP)	2.5

Figure 4.3-8. Vapor pressures of gasolines and finished petroleum products.

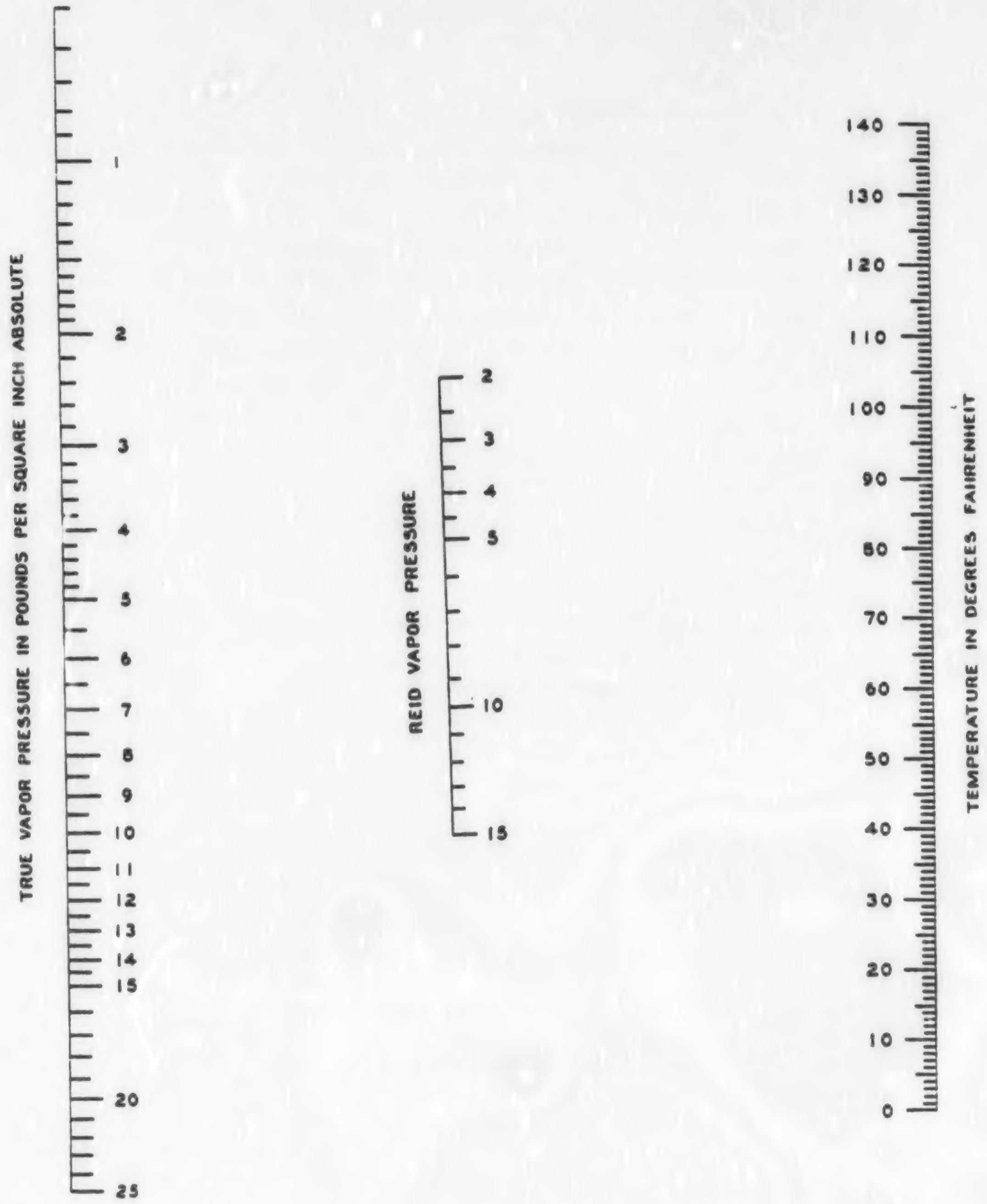


Figure 4.3-9. Vapor pressures of crude oil.

Table 4.3-2. PAINT FACTORS FOR FIXED ROOF TANKS[2]

Tank color		Paint factors (F_p)	
		Paint condition	
Roof	Shell	Good	Poor
White	White	1.00	1.15
Aluminum (specular)	White	1.04	1.18
White	Aluminum (specular)	1.16	1.24
Aluminum (specular)	Aluminum (specular)	1.20	1.29
White	Aluminum (diffuse)	1.30	1.38
Aluminum (diffuse)	Aluminum (diffuse)	1.39	1.46
White	Gray	1.30	1.38
Light gray	Light gray	1.33	1.44[a]
Medium gray	Medium gray	1.40	1.58[a]

[a] Estimated from the ratios of the seven preceding paint factors.

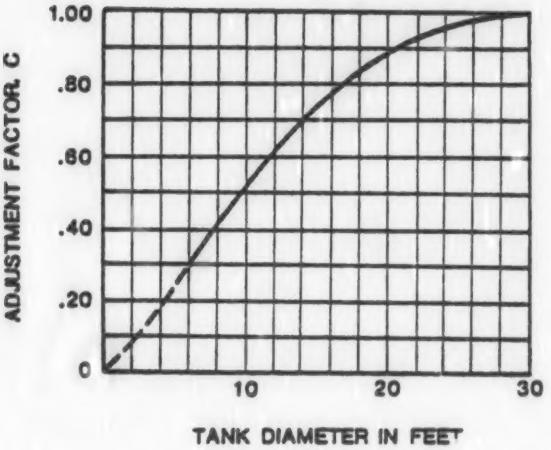


Figure 4.3-10. Adjustment factor (C) for small diameter tanks.

Fixed roof working losses can be estimated from:

$$L_W = 2.40 \times 10^{-2} M P K_N K_c \qquad (2)$$

where: L_W = Fixed roof working loss (lb/10^3 gal throughput).

M = Molecular weight of vapor in storage tank (lb/lb mole). see Table 4.3-1.

P = True vapor pressure at bulk liquid conditions (psia); see Figures 4.3-8, 4.3-9, or Table 4.3-1.

K_N = Turnover factor (dimensionless); see Figure 4.3-11.

K_c = Crude oil factor (dimensionless); see note.

Note: K_c = (0.84) for crude oil, K_c = (1.0) for gasoline and all other liquids.

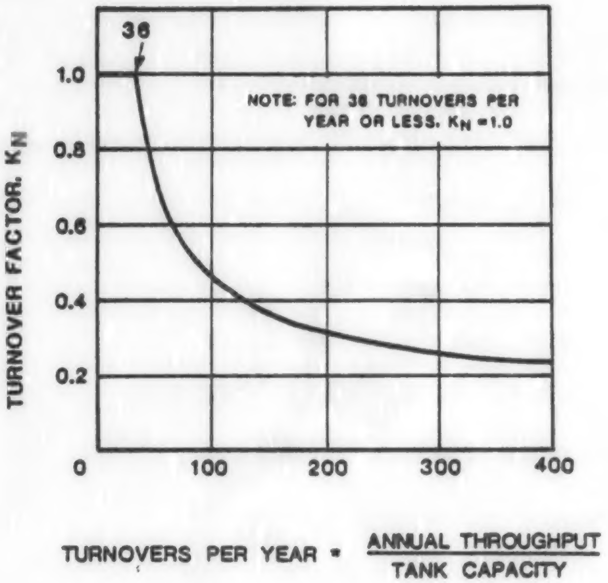


Figure 4.3-11. Turnover factor (K_N) for fixed roof tanks.

The fixed roof working loss (L_W) is the sum of the loading and unloading loss. API reports that special tank operating conditions may result in actual losses which are significantly greater or lower than the estimates provided by Equation (2).

The API recommends the use of these storage loss equations only for cases in which the stored petroleum liquids exhibit vapor pressures in the same range as gasolines. However, in the absence of any correlation developed specifically for naphthas, kerosenes, and fuel oils, it is recommended that these storage loss equations also be used for the storage of these heavier fuels.

The method most commonly used to control emissions from fixed roof tanks is a vapor recovery system that collects emissions from the storage vessels and converts them to liquid product. To recover vapor, one or a combination of four methods may be used: vapor/liquid absorption, vapor compression, vapor cooling, and vapor/solid adsorption. Overall control efficiencies of vapor recovery systems vary from 90 to 95 percent, depending on the method used, the design of the unit, the composition of vapors recovered, and the mechanical condition of the system.

Emissions from fixed roof tanks can also be controlled by the addition of an internal floating cover or covered floating roof to the existing fixed roof tank. API reports that this can result in an average loss reduction of 90 percent of the total evaporation loss sustained from a fixed roof tank.[8]

Evaporative emissions can be minimized by reducing tank heat input with water sprays, mechanical cooling, underground storage, tank insulation, and optimum scheduling of tank turnovers.

4.3.2.2 Floating Roof Tanks[3,7] - Floating roof standing storage losses can be estimated from:

$$L_S = 9.21 \times 10^{-3} M \left[\frac{P}{14.7 - P}\right]^{0.7} D^{1.5} V_w^{0.7} K_t K_s K_p K_c \qquad (3)$$

where: L_S = Floating roof standing storage loss (lb/day).

M = Molecular weight of vapor in storage tank (lb/lb mole); see Table 4.3-1.

P = True vapor pressure at bulk liquid conditions (psia); see Figures 4.3-8, 4.3-9, or Table 4.3-1.

D = Tank diameter (ft); see note (1).

V_w = Average wind velocity (mi/hr); see note (2).

K_t = Tank type factor (dimensionless); see Table 4.3-3.

K_s = Seal factor (dimensionless); see Table 4.3-3.

K_p = Paint factor (dimensionless); see Table 4.3-3.

K_c = Crude oil factor (dimensionless); see note (3).

Note: (1) For $D \geq 150$, use $D\sqrt{150}$ instead of $D^{1.5}$

(2) API correlation was derived for minimum wind velocity of 4 mph. If $V_w \leq 4$ mph, use $V_w = 4$mph.

(3) $K_c = (0.84)$ for crude oil, $K_c = (1.0)$ for all other liquids.

API reports that standing storage losses from gasoline and crude oil storage calculated from Equation (3) will not deviate from the actual losses by more than ±25 percent for tanks in good condition under normal operation. However, losses may exceed the calculated amount if the seals are in poor condition. Although the API recommends the use of these correlations only for petroleum liquids exhibiting vapor pressures in the range of gasoline and crude oils, in the absence of better correlations, these correlations are also recommended with caution for use with heavier naphthas, kerosenes, and fuel oils.

Table 4.3-3. TANK, TYPE, SEAL, AND PAINT FACTORS FOR FLOATING ROOF TANKS[2]

Tank type	K_t	Seal type	K_s
Welded tank with pan or pontoon roof, single or double seal	0.045	Tight fitting (typical of modern metallic and non-metallic seals)	1.00
Riveted tank with pontoon roof, double seal	0.11	Loose fitting (typical of seals built prior to 1942)	1.33
		Paint color of shell and roof	K_p
Riveted tank with pontoon roof, single seal	0.13	Light gray or aluminum	1.0
Riveted tank with pan roof, double seal	0.13	White	0.9
Riveted tank with pan roof, single seal	0.14		

API has developed a correlation based on laboratory data for calculating floating roof withdrawal loss for gasoline storage.[5] Floating roof withdrawal loss for gasoline can be estimated from:

$$L_{WD} = \frac{22.4\ d\ C_F}{D} \qquad (4)$$

where: L_{WD} = Floating roof gasoline withdrawal loss (lb/10^3 gal throughput).

d = Density of stored liquid at bulk liquid conditions (lb/gal); see Table 4.3-1.

C_F = Tank construction factor (dimensionless); see note.

D = Tank diameter (ft).

Note: C_F = (0.02) for steel tanks, C_F = (1.0) for gunite-lined tanks.

Because Equation (4) was derived from gasoline data, its applicability to other stored liquids is uncertain. No estimate of accuracy of Equation (4) has been given.

API has not presented any correlations that specifically pertain to internal floating covers or covered floating roofs. Currently, API recommends the use of Equations (3) and (4) with a wind speed of 4 mph for calculating the losses from internal floating covers and covered floating roofs.

Evaporative emissions from floating roof tanks can be minimized by reducing tank heat input.

4.3.2.3 Variable Vapor Space Systems[4,7]. Variable vapor space system filling losses can be estimated from:

$$L_V = (2.40 \times 10^{-2}) \frac{M P}{V_1} \left[(V_1) - (0.25\ V_2\ N) \right] \qquad (5)$$

where: L_V = Variable vapor space filling loss (lb/10^3 gal throughput).

M = Molecular weight of vapor in storage tank (lb/lb mole); see Table 4.3-1.

P = True vapor pressure at bulk liquid conditions (psia); see Figures 4.3-8, 4.3-9, or Table 4.3-1.

V_1 = Volume of liquid pumped into system: throughput (bbl).

V_2 = Volume expansion capacity of system (bbl); see note (1).

N = Number of transfers into system (dimensionless); see note (2).

Note: (1) V is the volume expansion capacity of the variable vapor space achieved by roof-lifting or diaphragm-flexing.

(2) N is the number of transfers into the system during the time period that corresponds to a throughput of V_1.

The accuracy of Equation (5) is not documented; however, API reports that special tank operating conditions may result in actual losses which are significantly different from the estimates provided by Equation (5). It should also be noted that, although not developed for use with heavier petroleum liquids such as kerosenes and fuel oils, Equation (5) is recommended for use with heavier petroleum liquids in the absence of better data.

Evaporative emissions from variable vapor space tanks are negligible and can be minimized by optimum scheduling of tank turnovers and by reducing tank heat input. Vapor recovery systems can be used with variable vapor space systems to collect and recover filling losses.

Vapor recovery systems capture hydrocarbon vapors displaced during filling operations and recover the hydrocarbon vapors by the use of refrigeration, absorption, adsorption, and/or compression. Control efficiencies range from 90 to 98 percent, depending on the nature of the vapors and the recovery equipment used.

4.3.2.4 Pressure Tanks - Pressure tanks incur vapor losses when excessive internal pressures result in relief valve venting. In some pressure tanks vapor venting is a design characteristic, and the vented vapors must be routed to a vapor recovery system. However, for most pressure tanks vapor venting is not a normal occurrence, and the tanks can be considered closed systems. Fugitive losses are also associated with pressure tanks and their equipment, but with proper system maintenance they are insignificant. Correlations do not exist for estimating vapor losses from pressure tanks.

4.3.3 Emission Factors

Equations (1) through (5) can be used to estimate evaporative losses, provided the respective parameters are known. For those cases where such parameters are unknown, Table 4.3-4 provides emission factors for the typical systems and conditions. It should be emphasized that these emission factors are rough estimates at best for storage of liquids other than gasoline and crude oil, and for storage conditions other than the ones they are based upon. In areas where storage sources contribute a substantial portion of the total evaporative emissions or where they are major factors affecting the air quality, it is advisable to obtain the necessary parameters and to calculate emission estimates using Equations (1) through (5).

Table 4.3-4. EVAPORATIVE EMISSION FACTORS FOR STORAGE TANKS WITHOUT CONTROLS[2-4,6,7]

Product Stored	Fixed roof tanks						Floating roof tanks						Variable vapor space tanks	
	Breathing loss						Standing storage loss						10,500 bbl	
	"New tank" conditions		"Old tank" conditions		Working loss		"New tank" conditions		"Old tank" conditions		Withdrawal loss		Filling loss	
	lb/day-10^3 gal	kg/day-10^3 liters	lb/day-10^3 gal	kg/day-10^3 liters	lb/10^3 gal throughput	kg/10^3 liters throughput	lb/day-10^3 gal	kg/day-10^3 liters	lb/day-10^3 gal	kg/day-10^3 liters	lb/10^3 gal throughput	kg/10^3 liters throughput	lb/10^3 gal throughput	kg/10^3 liters throughput
Fuels - 67,000 bbl tanks														
1. Gasoline RVP 13	0.30	0.036	0.34	0.041	10.0	1.2	0.044	0.0052	0.10	0.012	0.023	0.0028	9.6	1.2
2. Gasoline RVP 10	0.23	0.028	0.26	0.031	8.2	0.99	0.033	0.0040	0.078	0.0094	0.023	0.0028	7.7	0.93
3. Gasoline RVP 7	0.16	0.019	0.18	0.022	5.7	0.68	0.023	0.0028	0.055	0.0066	0.023	0.0028	5.4	0.65
4. Crude oil RVP 5	0.064	0.0077	0.073	0.0088	2.8	0.34	0.012	0.0014	0.028	0.0034			Not used	Not used
5. Jet naphtha (JP-4)	0.086	0.010	0.098	0.011	2.5	0.30	0.012	0.0014	0.028	0.0034			2.3	0.28
6. Jet kerosene	0.0043	0.00052	0.0049	0.00059	0.027	0.0032	0.00054	0.000065	0.0013	0.00016			0.025	0.0030
7. Distillate fuel no. 2	0.0039	0.00047	0.0044	0.00053	0.023	0.0028	0.00049	0.000058	0.0011	0.00014			0.022	0.0026
8. Residual oil no. 6	0.00016	0.000019	0.00018	0.000022	0.00018	0.000022	0.000018	0.0000022	0.000043	0.0000052			0.00017	0.000020
Fuels - 250,000 bbl tanks														
9. Gasoline RVP 13	0.22	0.026	0.25	0.030	10.0	1.2	0.025	0.0030	0.057	0.0068	0.013	0.0015	Not used	Not used
10. Gasoline RVP 10	0.17	0.020	0.19	0.023	8.2	0.99	0.019	0.0023	0.044	0.0053	0.013	0.0015	Not used	Not used
11. Gasoline RVP 7	0.12	0.014	0.13	0.016	5.7	0.68	0.013	0.0016	0.031	0.0037	0.013	0.0015	Not used	Not used
12. Crude oil RVP 5	0.046	0.0055	0.052	0.0062	2.8	0.34	0.0077	0.0092	0.018	0.0022			Not used	Not used
13. Jet naphtha (JP-4)	0.062	0.0074	0.071	0.0085	2.5	0.30	0.0068	0.00082	0.016	0.0019			Not used	Not used
14. Jet kerosene	0.0031	0.00037	0.0035	0.00042	0.027	0.0032	0.00031	0.000037	0.00074	0.000089			Not used	Not used
15. Distillate fuel no. 2	0.0028	0.00034	0.0032	0.00038	0.023	0.0028	0.00028	0.000034	0.00068	0.000082			Not used	Not used
16. Residual fuel no. 6	0.00012	0.000014	0.00014	0.000017	0.00018	0.000022	0.000010	0.0000012	0.000024	0.0000029			Not used	Not used
Petrochemicals* - 67,000 bbl tanks														
17. Acetone	0.12	0.014	0.14	0.016	4.0	0.48	0.017	0.0020	0.039	0.0047			3.8	0.45
18. Acrylonitrile	0.060	0.0072	0.068	0.0082	1.8	0.21	0.0084	0.0010	0.020	0.0024			1.7	0.20
19. Benzene	0.079	0.0094	0.090	0.011	2.2	0.27	0.011	0.0013	0.026	0.0031			2.1	0.25
20. Carbon disulfide	0.24	0.029	0.28	0.033	8.8	1.1	0.035	0.0042	0.083	0.0099			8.2	0.98
21. Carbon tetrachloride	0.17	0.021	0.20	0.024	5.2	0.62	0.024	0.0029	0.056	0.0069			4.8	0.58
22. Chloroform	0.21	0.025	0.24	0.029	7.1	0.86	0.030	0.0036	0.071	0.0085			6.7	0.80
23. Cyclohexane	0.085	0.010	0.096	0.012	2.4	0.29	0.012	0.0014	0.028	0.0034			2.3	0.27
24. 1,2-Dichlorethane	0.087	0.010	0.10	0.012	2.4	0.28	0.012	0.0014	0.029	0.0034			2.2	0.27
25. Ethyl acetate	0.083	0.010	0.095	0.011	2.3	0.28	0.012	0.0014	0.027	0.0033			2.2	0.26
26. Ethyl alcohol	0.028	0.0034	0.032	0.0038	0.66	0.079	0.0039	0.00046	0.0091	0.0011			0.62	0.074
27. Isopropyl alcohol	0.031	0.0038	0.036	0.0043	0.72	0.086	0.0043	0.00052	0.010	0.0012			0.68	0.082
28. Methyl alcohol	0.036	0.0044	0.042	0.0050	1.1	0.13	0.0051	0.00061	0.012	0.0014			1.0	0.12
29. Methylene chloride	0.31	0.037	0.35	0.042	11.0	1.3	0.044	0.0053	0.10	0.012			10.0	1.2
30. Methyl-ethyl-ketone	0.073	0.0087	0.083	0.0099	2.1	0.25	0.010	0.0012	0.024	0.0029			1.9	0.23
31. Methyl methacrylate	0.038	0.0046	0.043	0.0052	0.72	0.086	0.0051	0.00061	0.012	0.0015			0.68	0.082
32. 1,1,1-Trichloroethane	0.17	0.020	0.19	0.023	5.1	0.61	0.023	0.0028	0.055	0.0066			4.8	0.58
33. Trichloroethylene	0.11	0.013	0.12	0.014	2.8	0.34	0.015	0.0018	0.035	0.0042			2.6	0.31
34. Toluene	0.035	0.0042	0.040	0.0048	0.66	0.079	0.0048	0.00058	0.011	0.0014			0.62	0.074
35. Vinyl acetate	0.092	0.011	0.10	0.013	2.7	0.32	0.013	0.0016	0.030	0.0037			2.5	0.30

*Due to safety and health regulations, toxicity, and value of these petrochemicals, they are normally stored in tanks with vapor recovery controls which are 90 to 98 percent efficient.

Emission factors based on the following parameters

Ambient conditions:
Storage temperature: 60°F (15.6°C).
Daily ambient temperature change: 15°F (8.3°C)
Wind velocity: 10 mi/hr (4.5 m/sec.)

Typical fixed roof tanks:
Outage: 50 percent of tank height.
Turnovers per year (N): 30 for crude, 13 for all other liquids.
Paint factor (F_p): New tank-white paint-1.00.
Old tank-white/aluminum paint-1.14.

For 67,000 bbl tankage (10.7×10^6 liters)
Height: 48 ft. (14.6m)
Diameter: 110 ft. (33.5m)

For 250,000 bbl tankage (39.7×10^6 liters)
Height: 44 ft. (11.4m)
Diameter: 200 ft. (60.8m)

Emission factors based on the following parameters

Typical floating roof tanks
Paint factor (K_p): New tank-white paint-0.090.
Old tank-white/aluminum paint-0.95.
Seal factor (K_s): New tank-modern seals-1.00.
Old tank-50 percent old seals-1.14.
Tank type factor (K_t): New tank-welded-0.045.
Old tank-50 percent riveted-0.088.

Typical variable space tank
Diameter: 50 ft. (15.2m)
Height: 30 ft. (9.1m)
Capacity: 10,500 bbl (1.67×10^6 liters)
Turnovers per year (N): 6
Volume expansion capacity: one fourth of liquid capacity: 2625 bbl (0.42×10^6 liters).

4.3.3.1 **Sample Calculation - Breathing losses from a fixed roof storage tank would be calculated as follows, using Equation (1).**

Design basis:

Tank capacity - 100,000 bbl.
Tank diameter - 125 ft.
Tank height - 46 ft.
Average diurnal temperature change - 15°F.
Gasoline RVP - 9 psia.
Gasoline temperature - 70°F.
Specular aluminum painted tank.
Roof slope is 0.1 ft/ft.

Fixed roof tank breathing loss equation:

$$L_B = 2.21 \times 10^{-4} M \left[\frac{P}{14.7 - P}\right]^{0.68} D^{1.73}\ H^{0.51}\ \Delta T^{0.50}\ F_p\ C\ K_c$$

where: M = **Molecular weight of gasoline vapors (see Table 4.3-1) = 66.**

P = **True vapor of gasoline (see Figure 4.3-8) = 5.6 psia.**

D = **Tank diameter = 125 ft.**

ΔT = **average diurnal temperature change = 15°F.**

F_p = **paint factor (see Table 4.3-2) = 1.20.**

C = **tank diameter adjustment factor (see Figure 4.3-10) = 1.0.**

K_c = **crude oil factor (see note for equation (1)) = 1.0.**

H = **average vapor space height. For a tank which is filled completely and emptied, the average liquid level is 1/2 the tank rim height, or 23 ft. The effective cone height is 1/3 of the cone height. The roof slope is 0.1 ft/ft and the tank radius is 62.5 ft. Effective cone height = (62.5 ft) (0.1 ft/ft) (1/3) = 2.08 ft.**

H = **average vapor space height = 23 ft + 2 ft = 25 ft.**

Therefore:

$$L_B = 2.21 \times 10^{-4}\,(66) \left[\frac{5.6}{14.7 - 5.6}\right]^{0.68} (125)^{1.73}\ (25)^{0.51}\ (15)^{0.50}\ (1.2)(1.0)(1.0)$$

$$L_B = 1068 \text{ lb/day}$$

References for Section 4.3

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4.4 TRANSPORTATION AND MARKETING OF PETROLEUM LIQUIDS[1]

by Charles C. Masser

4.4.1 Process Description

As Figure 4.4-1 indicates, the transportation and marketing of petroleum liquids involves many distinct operations, each of which represents a potential source of hydrocarbon evaporation loss. Crude oil is transported from production operations to the refinery via tankers, barges, tank cars, tank trucks, and pipelines. In the same manner, refined petroleum products are conveyed to fuel marketing terminals and petrochemical industries by tankers, barges, tank cars, tank trucks, and pipelines. From the fuel marketing terminals, the fuels are delivered via tank trucks to service stations, commercial accounts, and local bulk storage plants. The final destination for gasoline is usually a motor vehicle gasoline tank. A similar distribution path may also be developed for fuel oils and other petroleum products.

4.4.2 Emissions and Controls

Evaporative hydrocarbon emissions from the transportation and marketing of petroleum liquids may be separated into four categories, depending on the storage equipment and mode of transportation used:

1. Large storage tanks: Breathing, working, and standing storage losses.
2. Marine vessels, tank cars, and tank trucks: Loading, transit, and ballasting losses.
3. Service stations: Bulk fuel drop losses and underground tank breathing losses.
4. Motor vehicle tanks: Refueling losses.

(In addition, evaporative and exhaust emissions are also associated with motor vehicle operation. These topics are discussed in Chapter 3.)

4.4.2.1 Large Storage Tanks - Losses from storage tanks are thoroughly discussed in Section 4.3.

4.4.2.2 Marine Vessels, Tank Cars, and Tank Trucks - Losses from marine vessels, tank cars, and tank trucks can be categorized into loading losses, transit losses, and ballasting losses.

Loading losses are the primary source of evaporative hydrocarbon emissions from marine vessel, tank car, and tank truck operations. Loading losses occur as hydrocarbon vapors residing in empty cargo tanks are displaced to the atmosphere by the liquid being loaded into the cargo tanks. The hydrocarbon vapors displaced from the cargo tanks are a composite of (1) hydrocarbon vapors formed in the empty tank by evaporation of residual product from previous hauls and (2) hydrocarbon vapors generated in the tank as the new product is being loaded. The quantity of hydrocarbon losses from loading operations is, therefore, a function of the following parameters:

- Physical and chemical characteristics of the previous cargo.
- Method of unloading the previous cargo.

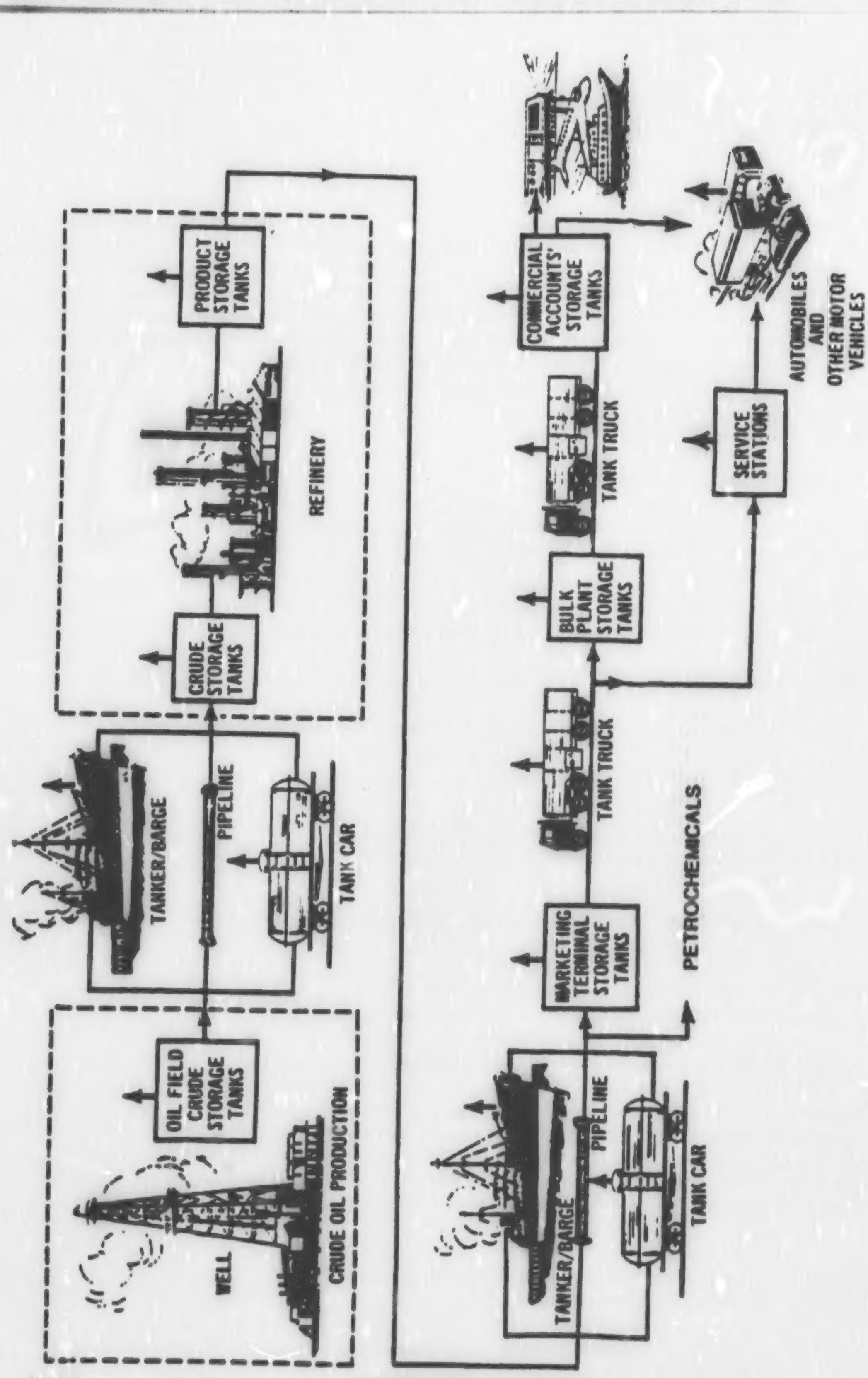
WELL
CRUDE OIL PRODUCTION
OIL FIELD CRUDE STORAGE TANKS
TANKER/BARGE
PIPELINE
TANK CAR
CRUDE STORAGE TANKS
REFINERY
PRODUCT STORAGE TANKS
TANKER/BARGE
PIPELINE
TANK CAR
PETROCHEMICALS
MARKETING TERMINAL STORAGE TANKS
TANK TRUCK
BULK PLANT STORAGE TANKS
TANK TRUCK
COMMERCIAL ACCOUNTS' STORAGE TANKS
SERVICE STATIONS
AUTOMOBILES AND OTHER MOTOR VEHICLES

Figure 4.4-1. Flowsheet of petroleum production, refining, and distribution systems. (Sources of organic evaporative emissions are indicated by vertical arrows.)

- Operations during the transport of the empty carrier to the loading terminal.
- Method of loading the new cargo.
- Physical and chemical characteristics of the new cargo.

The principal methods of loading cargo carriers are presented in Figures 4.4-2, 4.4-3, and 4.4-4. In the splash loading method, the fill pipe dispensing the cargo is only partially lowered into the cargo tank. Significant turbulence and vapor-liquid contacting occurs during the splash loading operation, resulting in high levels of vapor generation and loss. If the turbulence is high enough, liquid droplets will be entrained in the vented vapors.

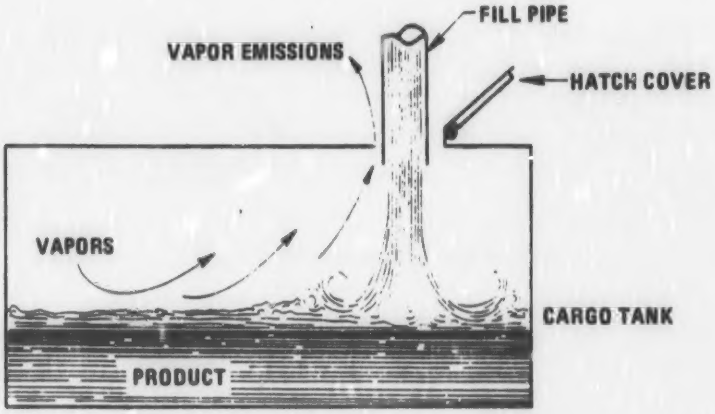
FILL PIPE
VAPOR EMISSIONS
HATCH COVER
VAPORS
CARGO TANK
PRODUCT

Figure 4.4-2. Splash loading method.

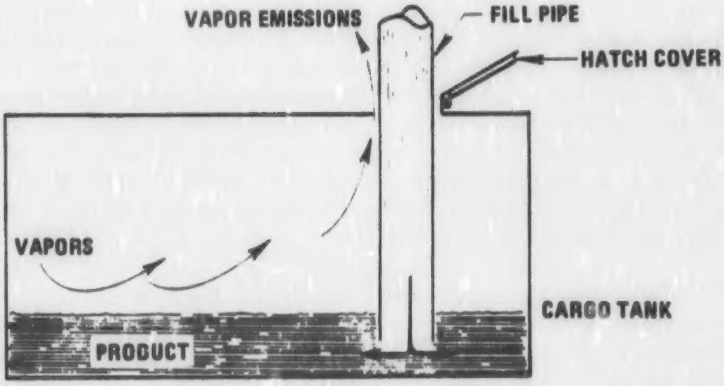
VAPOR EMISSIONS
FILL PIPE
HATCH COVER
VAPORS
CARGO TANK
PRODUCT

Figure 4.4-3. Submerged fill pipe.

A second method of loading is submerged loading. The two types of submerged loading are the submerged fill pipe method and the bottom loading method. In the submerged fill pipe method, the fill pipe descends almost to the bottom of the cargo tank. In the bottom loading method, the fill pipe enters the cargo tank from the bottom. During the major portion of both forms of submerged loading

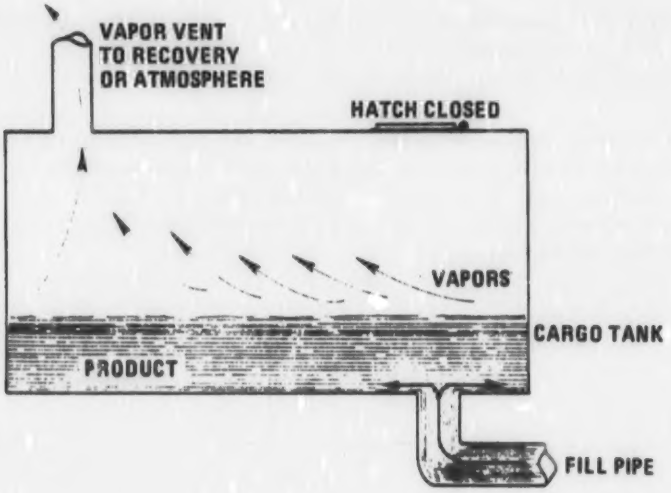

Figure 4.4-4. Bottom loading.

methods, the fill pipe opening is positioned below the liquid level. The submerged loading method significantly reduces liquid turbulence and vapor-liquid contacting, thereby resulting in much lower hydrocarbon losses than encountered during splash loading methods.

The history of a cargo carrier is just as important a factor in loading losses as the method of loading. Hydrocarbon emissions are generally lowest from a clean cargo carrier whose cargo tanks are free from vapors prior to loading. Clean cargo tanks normally result from either carrying a non-volatile liquid such as heavy fuel oils in the previous haul, or from cleaning or venting the empty cargo tank prior to loading operations. An additional practice, specific to marine vessels, that has significant impact on loading losses is ballasting. After unloading a cargo, empty tankers normally fill several cargo tanks with water to improve the tanker's stability on the return voyage. Upon arrival in port, this ballast water is pumped from the cargo tanks before loading the new cargo. The ballasting of cargo tanks reduces the quantity of vapor returning in the empty tanker, thereby reducing the quantity of vapors emitted during subsequent tanker loading operations.

In normal dedicated service, a cargo carrier is dedicated to the transport of only one product and does not clean or vent its tank between trips. An empty cargo tank in normal dedicated service will retain a low but significant concentration of vapors which were generated by evaporation of residual product on the tank surfaces. These residual vapors are expelled along with newly generated vapors during the subsequent loading operation.

Another type of cargo carrier is one in "dedicated balance service." Cargo carriers in dedicated balance service pick up vapors displaced during unloading operations and transport these vapors in the empty cargo tanks back to the loading terminal. Figure 4.4-5 shows a tank truck in dedicated vapor balance service unloading gasoline to an underground service station tank and filling up with displaced gasoline vapors to be returned to the truck loading terminal. The vapors in an empty cargo carrier in dedicated balance service are normally saturated with hydrocarbons.

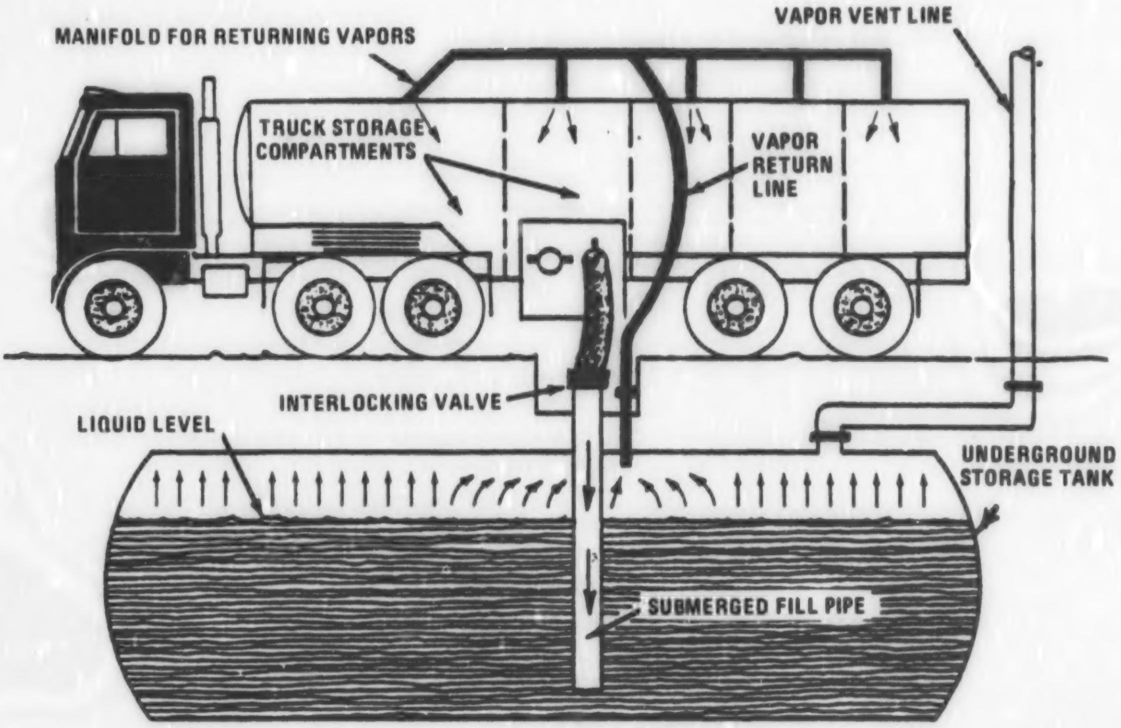
MANIFOLD FOR RETURNING VAPORS
VAPOR VENT LINE
TRUCK STORAGE COMPARTMENTS
VAPOR RETURN LINE
INTERLOCKING VALVE
LIQUID LEVEL
UNDERGROUND STORAGE TANK
SUBMERGED FILL PIPE

Figure 4.4-5. Tanktruck unloading into an underground service station storage tank. Tanktruck is practicing "vapor balance" form of vapor control.

Emissions from loading hydrocarbon liquid can be estimated (within 30 percent) using the following expression:

$$L_L = 12.46 \frac{SPM}{T} \qquad (1)$$

where: L_L = Loading loss, lb/10^3 gal of liquid loaded.

M = Molecular weight of vapors, lb/lb-mole (see Table 4.3-1).

P = True vapor pressure of liquid loading, psia (see Figures 4.3-8 and 4.3-9, and Table 4.3-1).

T = Bulk temperature of liquid loaded, °R.

S = A saturation factor (see Table 4.4-1).

The saturation factor (S) represents the expelled vapor's fractional approach to saturation and accounts for the variations observed in emission rates from the different unloading and loading methods. Table 4.4-1 lists suggested saturation factors (S).

Table 4.4-1. S FACTORS FOR CALCULATING PETROLEUM LOADING LOSSES

Cargo carrier	Mode of operation	S factor
Tank trucks and tank cars	Submerged loading of a clean cargo tank	0.50
	Splash loading of a clean cargo tank	1.45
	Submerged loading: normal dedicated service	0.60
	Splash loading: normal dedicated service	1.45
	Submerged loading: dedicated, vapor balance service	1.00
	Splash loading: dedicated, vapor balance service	1.00
Marine vessels[a]	Submerged loading: ships	0.2
	Submerged loading: barges	0.5

[a] To be used for products other than gasoline; use factors from Table 4.4-2 for marine loading of gasoline.

Recent studies on gasoline loading losses from ships and barges have led to the development of more accurate emission factors for these specific loading operations. These factors are presented in Table 4.4-2 and should be used instead of Equation (1) for gasoline loading operations at marine terminals.[2]

Ballasting operations are a major source of hydrocarbon emissions associated with unloading petroleum liquids at marine terminals. It is common practice for large tankers to fill several cargo tanks with water after unloading their cargo. This water, termed ballast, improves the stability of the empty tanker on rough seas during the subsequent return voyage. Ballasting emissions occur as hydrocarbon-laden air in the empty cargo tank is displaced to the atmosphere by ballast water being pumped into the empty cargo tank. Although ballasting practices vary quite a bit, individual cargo tanks are ballasted about 80 percent, and the total vessel is ballasted approximately 40 percent of capacity. Ballasting emissions from gasoline and crude oil tankers are approximately 0.8 and 0.6 lb/10^3 gal, respectively, based on total tanker capacity. These estimates are for motor gasolines and medium volatility crudes (RVP$\approx$5 psia).[2]

An additional emission source associated with marine vessel, tank car, and tank truck operations is transit losses. During the transportation of petroleum liquids, small quantities of hydrocarbon vapors are expelled from cargo tanks due to temperature and barometric pressure changes. The most significant transit loss is from tanker and barge operations and can be calculated using Equation (2).[3]

Table 4.4-2. HYDROCARBON EMISSION FACTORS FOR GASOLINE LOADING OPERATIONS

Vessel tank condition	Hydrocarbon emission factors					
	Ships		Ocean barges		Barges	
	Range	Average	Range	Average	Range	Average
Cleaned and vapor free						
$lb/10^3$ gal transferred	0 to 2.3	1.0	0 to 3	1.3	a	1.2
$kg/10^3$ liter transferred	0 to 0.28	0.12	0 to 0.36	0.16		0.14
Ballasted						
$lb/10^3$ gal transferred	0.4 to 3	1.6	0.5 to 3	2.1	b	b
$kg/10^3$ liter transferred	0.05 to 0.36	0.19	0.06 to 0.36	0.25		
Uncleaned - dedicated service						
$lb/10^3$ gal transferred	0.4 to 4	2.4	0.5 to 5	3.3	1.4 to 9	4.0
$kg/10^3$ liter transferred	0.05 to 0.48	0.29	0.06 to 0.60	0.40	0.17 to 1.08	0.48
Average cargo tank condition						
$lb/10^3$ gal transferred	a	1.4	a	a	a	4.0
$kg/10^3$ liter transferred		0.17				0.48

[a] These values are not available.

[b] Barges are not normally ballasted.

$$L_T = 0.1\ PW \qquad (2)$$

where: L_T = Transit loss, lb/week-10^3 gal transported.

P = True vapor pressure of the transported liquid, psia (see Figures 4.3-8 and 4.3-9, and Table 4.3-1).

W = Density of the condensed vapors, lb/gal (see Table 4.3-1).

In the absence of specific inputs for Equations (1) and (2), typical evaporative hydrocarbon emissions from loading operations are presented in Table 4.4-3. It should be noted that, although the crude oil used to calculate the emission values presented in Table 4.4-3 has an RVP of 5, the RVP of crude oils can range over two orders of magnitude. In areas where loading and transportation sources are major factors affecting the air quality it is advisable to obtain the necessary parameters and to calculate emission estimates from Equations (1) and (2).

Control measures for reducing loading emissions include the application of alternate loading methods producing lower emissions and the application of vapor recovery equipment. Vapor recovery equipment captures hydrocarbon vapors displaced during loading and ballasting operations and recovers the hydrocarbon vapors by the use of refrigeration, absorption, adsorption, and/or compression. Figure 4.4-6 demonstrates the recovery of gasoline vapors from tank trucks during loading operation at bulk terminals. Control efficiencies range from 90 to 98 percent depending on the nature of the vapors and the type of recovery equipment employed.[4]

Table 4.4-3. HYDROCARBON EMISSION FACTORS FOR PETROLEUM LIQUID TRANSPORTATION AND MARKETING SOURCES

Emission source	Product emission factors					
	Gasoline	Crude oil	Jet naphtha (JP-4)	Jet kerosene	Distillate oil No. 2	Residual oil No. 6
Tank cars/trucks						
Submerged loading-normal service						
lb/10^3 gal transferred	5	3	1.5	0.02	0.01	0.0001
kg/10^3 liters transferred	0.6	0.4	0.18	0.002	0.001	0.00001
Splash loading-normal service						
lb/10^3 gal transferred	12	7	4	0.04	0.03	0.0003
kg/10^3 liters transferred	1.4	0.8	0.5	0.005	0.004	0.00004
Submerged loading-balance service						
lb/10^3 gal transferred	8	5	2.5	a	a	a
kg/10^3 liters transferred	1.0	0.6	0.3			
Splash loading-balance service						
lb/10^3 gal transferred	8	5	2.5	a	a	a
kg/10^3 liters transferred	1.0	0.6	0.3			
Marine vessels						
Loading tankers						
lb/10^3 gal transferred	b	0.7	0.5	0.005	0.005	0.00004
kg/10^3 liters transferred		0.08	0.06	0.0006	0.0006	5×10^{-6}
Loading barges						
lb/10^3 gal transferred	b	1.7	1.2	0.013	0.012	0.00009
kg/10^3 liters transferred		0.20	0.14	0.0016	0.0014	1.1×10^{-5}
Tanker ballasting						
lb/10^3 gal cargo capacity	0.8	0.6	c	c	c	c
kg/10^3 liters cargo capacity	0.10	0.07				
Transit						
lb/week-10^3 gal transported	3	1	0.7	0.02	0.005	3×10^{-5}
kg/week-10^3 liters transported	0.4	0.1	0.08	0.002	0.0006	4×10^{-6}

1. Emission factors are calculated for dispensed fuel temperature of 60°F.
2. The example gasoline has an RVP of 10 psia.
3. The example crude oil has an RVP of 5 psia.

a. Not normally used.
b. See Table 4.4-2 for these emission factors.
c. Not Available.

Emissions from controlled loading operations can be calculated by multiplying the uncontrolled emission rate calculated in Equations (1) and (2) by the control efficiency term:

$$\left[1 - \frac{\text{efficiency}}{100}\right]$$

4.4.2.3 Sample Calculation - Loading losses from a gasoline tank truck in dedicated balance service and practicing vapor recovery would be calculated as follows using Equation (1).

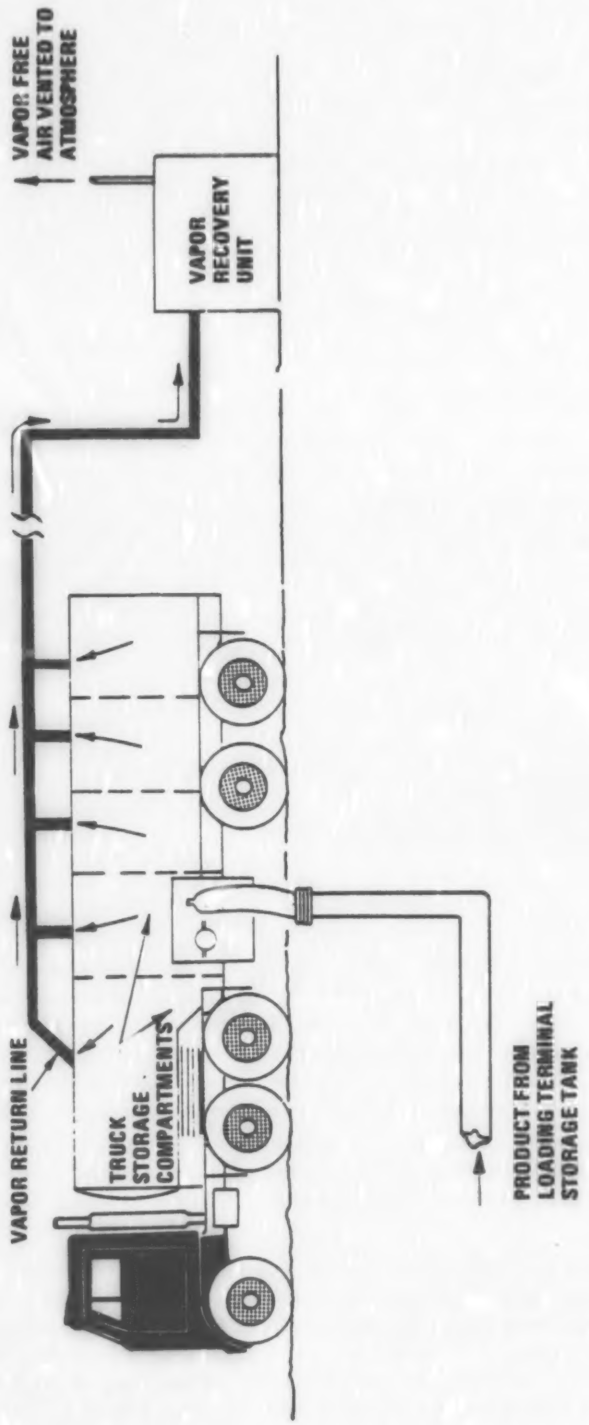
VAPOR FREE AIR VENTED TO ATMOSPHERE
VAPOR RECOVERY UNIT
VAPOR RETURN LINE
TRUCK STORAGE COMPARTMENTS
PRODUCT FROM LOADING TERMINAL STORAGE TANK

Figure 4.4-6. Tanktruck loading with vapor recovery.

Design basis:

Tank truck volume is 8000 gallons
Gasoline RVP is 9 psia
Dispensing temperature is 80°F
Vapor recovery efficiency is 95%

Loading loss equation:

$$L_L = 12.46 \frac{SPM}{T} \left(1 - \frac{eff}{100}\right)$$

where: S = Saturation factor (see Table 4.4-1) = 1.0
P = True vapor pressure of gasoline (see Figure 4.3-8) = 6.6 psia
M = Molecular weight of gasoline vapors (see Table 4.3-1) ≈66
T = Temperature of gasoline = 540°R
eff = The control efficiency = 95%

$$L_L = 12.46 \frac{(1.0)(6.6)(66)}{540} \left(1 - \frac{95}{100}\right)$$

$$= 0.50 \text{ lb}/10^3 \text{ gal}$$

Total loading losses are

$(0.50 \text{ lb}/10^3 \text{ gal}) (8.0 \times 10^3 \text{ gal}) = 4.0$ lb of hydrocarbon

4.4.2.4 Service Stations - Another major source of evaporative hydrocarbon emissions is the filling of underground gasoline storage tanks at service stations. Normally, gasoline is delivered to service stations in large (8000 gallon) tank trucks. Emissions are generated when hydrocarbon vapors in the underground storage tank are displaced to the atmosphere by the gasoline being loaded into the tank. As with other loading losses, the quantity of the service station tank loading loss depends on several variables including the size and length of the fill pipe, the method of filling, the tank configuration, and the gasoline temperature, vapor pressure, and composition. An average hydrocarbon emission rate for submerged filling is 7.3 lb/10^3 gallons of transferred gasoline, and the rate for splash filling is 11.5 lb/10^3 gallons of transferred gasoline (Table 4.4-4).[4]

Emissions from underground tank filling operations at service stations can be reduced by the use of the vapor balance system (Figure 4.4-5). The vapor balance system employs a vapor return hose which returns gasoline vapors displaced from the underground tank to the tank truck storage compartments being emptied. The control efficiency of the balance system ranges from 93 to 100 percent. Hydrocarbon emissions from underground tank filling operations at a service station employing the vapor balance system and submerged filling are not expected to exceed 0.3 lb/10^3 gallons of transferred gasoline.

Table 4.4-4. HYDROCARBON EMISSIONS FROM GASOLINE SERVICE STATION OPERATIONS

Emission source	Emission rate	
	lb/10^3 gal throughput	kg/10^3 liters throughput
Filling underground tank		
Submerged filling	7.3	0.88
Splash filling	11.5	1.38
Balanced submerged filling	0.3	0.04
Underground tank breathing	1	0.12
Vehicle refueling operations		
Displacement losses (uncontrolled)	9	1.08
Displacement losses (controlled)	0.9	0.11
Spillage	0.7	0.084

A second source of hydrocarbon emissions from service stations is underground tank breathing. Breathing losses occur daily and are attributed to temperature changes, barometric pressure changes, and gasoline evaporation. The type of service station operation also has a large impact on breathing losses. An average breathing emission rate is 1 lb/10^3 gallons throughput.[5]

4.4.2.5 Motor Vehicle Refueling - An additional source of evaporative hydrocarbon emissions at service stations is vehicle refueling operations. Vehicle refueling emissions are attributable to vapors displaced from the automobile tank by dispensed gasoline and to spillage. The quantity of displaced vapors is dependent on gasoline temperature, auto tank temperature, gasoline RVP, and dispensing rates. Although several correlations have been developed to estimate losses due to displaced vapors, significant controversy exists concerning these correlations. It is estimated that the hydrocarbon emissions due to vapors displaced during vehicle refueling average 9 lb/10^3 gallons of dispensed gasoline.[4,5]

The quantity of spillage loss is a function of the type of service station, vehicle tank configuration, operator technique, and operation discomfort indices. An overall average spillage loss is 0.7 lb/10^3 gallons of dispensed gasoline.[6]

Control methods for vehicle refueling emissions are based on conveying the vapors displaced from the vehicle fuel tank to the underground storage tank vapor space through the use of a special hose and nozzle (Figure 4.4-7). In the "balance" vapor control system, the vapors are conveyed by natural pressure differentials established during refueling. In "vacuum assist" vapor control systems, the conveyance of vapors from the auto fuel tank to the underground fuel tank is assisted by a vacuum pump. The overall control efficiency of vapor control systems for vehicle refueling emissions is estimated to be 88 to 92 percent.[4]

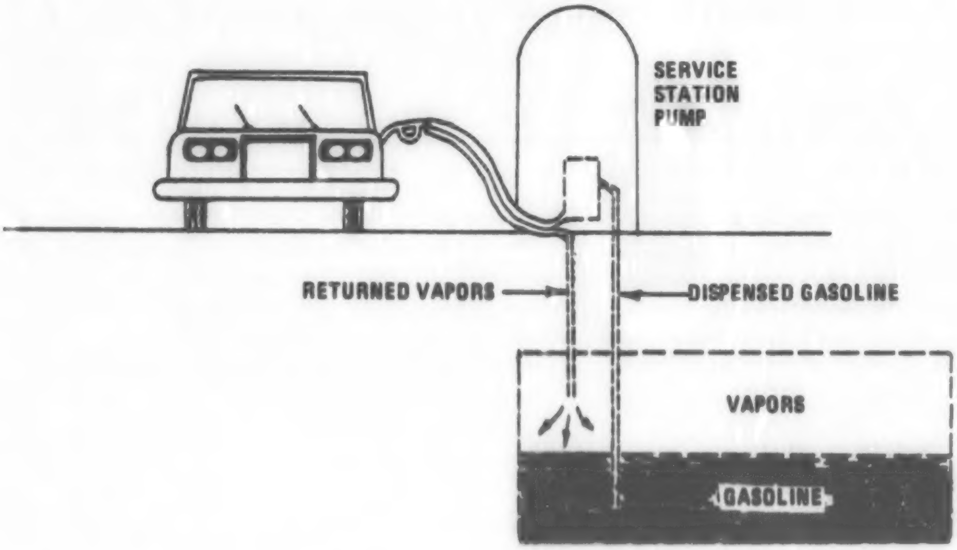

Figure 4.4-7. Automobile refueling vapor-recovery system.

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2. Burklin, Clinton E. et al. Background Information on Hydrocarbon Emissions From Marine Terminal Operations, 2 Vols., EPA Report No. 450/3-76-038a and b. Research Triangle Park, N.C. November 1976.

3. American Petroleum Inst., Evaporation Loss Committee. Evaporation Loss From Tank Cars, Tank Trucks, and Marine Vessels. Washington, D.C. Bull. 2514. 1959.

4. Burklin, Clinton E. et al. Study of Vapor Control Methods For Gasoline Marketing Operations, 2 Vols. Radian Corporation. Austin, Texas. May 1975.

5. Scott Research Laboratories, Inc. Investigation Of Passenger Car Refueling Losses, Final Report, 2nd year program. EPA Report No. APTD-1453. Research Triangle Park, N.C. September 1972.

6. Scott Research Laboratories, Inc. Mathematical Expressions Relating Evaporative Emissions From Motor Vehicles To Gasoline Volatility, summary report. Plumsteadville, Pennsylvania. API Publication 4077. March 1971.

5. CHEMICAL PROCESS INDUSTRY

This section deals with emissions from the manufacture and use of chemicals or chemical products. Potential emissions from many of these processes are high, but because of the nature of the compounds they are usually recovered as an economic necessity. In other cases, the manufacturing operation is run as a closed system allowing little or no escape to the atmosphere.

In general, the emissions that reach the atmosphere from chemical processes are primarily gaseous and are controlled by incineration, adsorption, or absorption. In some cases, particulate emissions may also be a problem. The particulates emitted are generally extremely small and require very efficient treatment for removal. Emission data from chemical processes are sparse. It was therefore frequently necessary to make estimates of emission factors on the basis of material balances, yields, or similar processes.

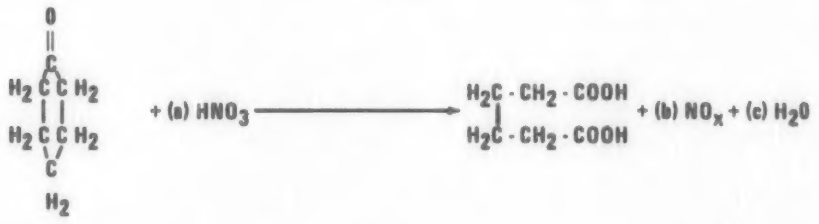
5.1 ADIPIC ACID

by Pam Canova

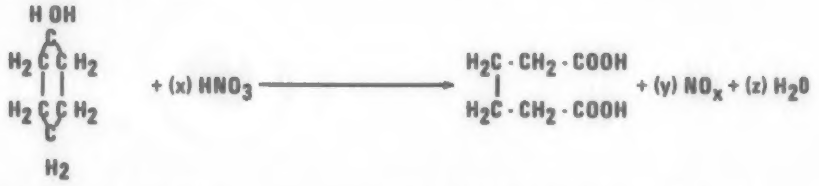
5.1.1 General[1,2]

Adipic acid, $HOOC(CH_2)_4COOH$, is a white crystalline solid used in the manufacture of synthetic fibers, coatings, plastics, urethane foams, elastomers, and synthetic lubricants. Ninety percent of all adipic acid produced in the United States is used in manufacturing Nylon 6,6. Cyclohexane is generally the basic raw material used to produce adipic acid; however, one plant uses cyclohexanone, which is a by-product of another process. Phenol has also been utilized, but has proved to be more expensive and less readily available than cyclohexane.

During adipic acid production, the raw material, cyclohexane or cyclohexanone, is transferred to a reactor, where it is oxidized at 260 to 330°F (130 to 170°C) to form a cyclohexanol/cyclohexanone mixture. The mixture is then transferred to a second reactor and oxidized with nitric acid and a catalyst (usually a mixture of cupric nitrate and ammonium vanadate) at 160 to 220°F (70 to 100°C) to form adipic acid. The chemistry of these reactions is shown below.



Cyclohexanone + Nitric acid ⟶ Adipic acid + Nitrogen oxides + Water



Cyclohexanol + Nitric acid ⟶ Adipic acid + Nitrogen oxides + Water

Dissolved NO_x gas plus any light hydrocarbon by-products are stripped from the adipic acid/nitric acid solution with air and steam. Various organic acid by-products, namely acetic acid, glutaric acid, and succinic acid, are also formed and may be recovered and sold by some plants.

The adipic acid/nitric acid solution is then chilled, and sent to a crystallizer where adipic acid crystals are formed. The solution is centrifuged to separate the crystals. The remaining solution is sent to another crystallizer, where any residual adipic acid is crystallized and centrifugally separated. The crystals from the two centrifuges are combined, dried, and stored. The remaining solution is distilled to recover nitric acid, which is routed back to the second reactor for re-use. Figure 5.1-1 presents a general schematic of the adipic acid manufacturing process.

5.1.2 Emissions and Controls

Nitrogen oxides, hydrocarbons, and carbon monoxide are the major pollutants produced in adipic acid production. The cyclohexane reactor is the largest source of CO and HC, and the nitric acid reactor is the predominant source of NO_x. Particulate emissions are low because baghouses are generally employed for maximum product recovery and air pollution control. Figure 5.1-1 shows the points of emission of these pollutants.

The most significant emissions of HC and CO come from the cyclohexane oxidation unit, which is equipped with high- and low-pressure scrubbers. Scrubbers have a 90 percent collection efficiency of HC and are used for economic reasons to recover expensive hydrocarbons as well as for pollution control. Thermal incinerators, flaring, and carbon absorbers can all be used to limit HC emissions from the cyclohexane oxidation unit with greater than 90 percent efficiency. CO boilers control CO emissions with 99.99 percent efficiency and HC emissions with practically 100 percent efficiency. The combined use of a CO boiler and a pressure scrubber results in essentially complete HC and CO control.

Three methods are presently used to control emissions from the NO_x absorber: water scrubbing, thermal reduction, and flaring or combustion in a powerhouse boiler. Water scrubbers have a low collection efficiency of approximately 70 percent because of the extended length of time needed to remove insoluble NO in the absorber offgas stream. Thermal reduction, in which offgases containing NO_x are heated to high temperatures and reacted with excess fuel in a reducing atmosphere, operates at up to 97.5 percent efficiency and is believed to be the most effective system of control. Burning offgas in a powerhouse or flaring has an estimated efficiency of 70 percent.

Emission factors for adipic acid manufacture are listed in Table 5.1-1.

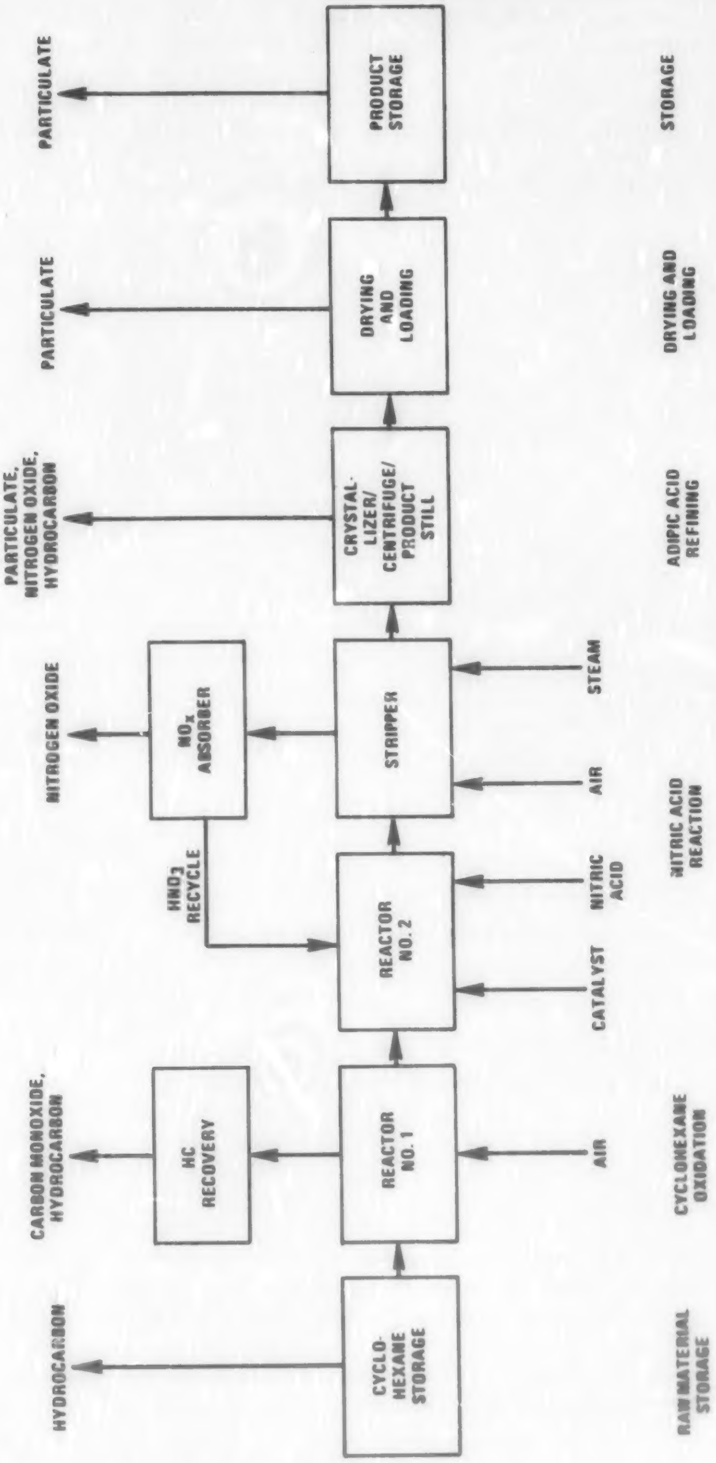

HYDROCARBON
CYCLO-HEXANE STORAGE
RAW MATERIAL STORAGE
CARBON MONOXIDE, HYDROCARBON
HC RECOVERY
REACTOR NO. 1
AIR
CYCLOHEXANE OXIDATION
HNO_3 RECYCLE
REACTOR NO. 2
CATALYST
NITRIC ACID
NITROGEN OXIDE
NO_x ABSORBER
STRIPPER
AIR
STEAM
NITRIC ACID REACTION
PARTICULATE, NITROGEN OXIDE, HYDROCARBON
CRYSTAL-LIZER/ CENTRIFUGE/ PRODUCT STILL
ADIPIC ACID REFINING
PARTICULATE
DRYING AND LOADING
DRYING AND LOADING
PARTICULATE
PRODUCT STORAGE
STORAGE

Figure 5.1-1. General flow diagram of adipic acid manufacturing process.

Table 5.1-1. EMISSION FACTORS FOR ADIPIC ACID MANUFACTURE[1,a]
EMISSION FACTOR RATING: B

Process	Particulate		Nitrogen oxides[b]		Hydrocarbon		Carbon monoxide	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Raw material storage								
Uncontrolled	0	0	0	0	2.2	1.1	0	0
Cyclohexane oxidation								
Uncontrolled[c]	0	0	0	0	40	20	115	58
W/boiler	0	0	0	0	Neg[l]	Neg	1	0.5
W/thermal incinerator[d]	0	0	0	0	Neg	Neg	Neg	Neg
W/flaring[e]	0	0	0	0	4	2	12	6
W/carbon absorber[f]	0	0	0	0	2	1	115	58
W/scrubber plus boiler	0	0	0	0	Neg	Neg	Neg	Neg
Nitric acid reaction								
Uncontrolled[g]	0	0	53	27	0	0	0	0
W/water scrubber[h]	0	0	16	8	0	0	0	0
W/thermal reduction[i]	0	0	1	0.5	0	0	0	0
W/flaring or combustion[h]	0	0	16	8	0	0	0	0
Adipic acid refining[j]								
Uncontrolled[k]	<0.1	<0.1	0.6	0.3	0.5	0.3	0	0
Adipic acid drying, loading, and storage								
Uncontrolled[k]	0.8	0.4	0	0	0	0	0	0

[a] Emission factors are in units of pounds of pollutant per ton and kilograms of pollutant per metric ton of adipic acid produced.

[b] NO_x is in the form of NO and NO_2. Although large quantities of N_2O are also produced, N_2O is not considered a criteria pollutant and is not, therefore, included in these factors.

[c] Uncontrolled emission factors are after scrubber processing since hydrocarbon recovery using scrubbers is an integral part of adipic acid manufacturing.

[d] A thermal incinerator is assumed to reduce HC and CO emissions by approximately 99.99%.

[e] A flaring system is assumed to reduce HC and CO emissions by 90%.

[f] A carbon absorber is assumed to reduce HC emissions by 94% and to be ineffective in reducing CO emissions.

[g] Uncontrolled emission factors are after NO_x absorber since nitric acid recovery is an integral part of adipic acid manufacturing.

[h] Based on estimated 70% control.

[i] Based on estimated 97.5% control.

[j] Refining includes chilling, crystallization, centrifuging, and purification.

[k] Particulate emission factors are after baghouse control device.

[l] Negligible.

References for Section 5.1

1. Screening Study to Determine Need for Standards of Performance for New Adipic Acid Plants. GCA/Technology Division, Bedford, Mass. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. 68-02-1316. July 1976.

2. Kirk-Othmer Encyclopedia of Chemical Technology. Adipic Acid. Vol. 1, 2nd Ed. New York, Interscience Encyclopedia, Inc. 1967. pp. 405-420.

5.2 AMMONIA

5.2.1 Process Description[1]

The manufacture of ammonia (NH_3) is accomplished primarily by the catalytic reaction of hydrogen and nitrogen at high temperatures and pressures. In a typical plant a hydrocarbon feed stream (usually natural gas) is desulfurized, mixed with steam, and catalytically reformed to carbon monoxide and hydrogen. Air is introduced into the secondary reformer to supply oxygen and provide a nitrogen to hydrogen ratio of 1 to 3. The gases then enter a two-stage shift converter that allows the carbon monoxide to react with water vapor to form carbon dioxide and hydrogen. The gas stream is next scrubbed to yield a gas containing less than 1 percent CO_2. A methanator may be used to convert quantities of unreacted CO to inert CH_4 before the gases, now largely nitrogen and hydrogen in a ratio of 1 to 3, are compressed and passed to the converter. Alternatively, the gases leaving the CO_2 scrubber may pass through a CO scrubber and then to the converter. The synthesis gases finally react in the converter to form ammonia.

5.2.2 Emissions and Controls[1]

When a carbon monoxide scrubber is used before sending the gas to the converter, the regenerator offgases contain significant amounts of carbon monoxide (73 percent) and ammonia (4 percent). This gas may be scrubbed to recover ammonia and then burned to utilize the CO fuel value.[2]

The converted ammonia gases are partially recycled, and the balance is cooled and compressed to liquefy the ammonia. The noncondensable portion of the gas stream, consisting of unreacted nitrogen, hydrogen, and traces of inerts such as methane, carbon monoxide, and argon, is largely recycled to the converter. To prevent the accumulation of these inerts, however, some of the noncondensable gases must be purged from the system.

The purge or bleed-off gas stream contains about 15 percent ammonia.[2] Another source of ammonia is the gases from the loading and storage operations. These gases may be scrubbed with water to reduce the atmospheric emissions. In addition, emissions of CO and ammonia can occur from plants equipped with CO-scrubbing systems. Emission factors are presented in Table 5.2-1.

Table 5.2-1. EMISSION FACTORS FOR AMMONIA MANUFACTURING WITHOUT CONTROL EQUIPMENT[a]
EMISSION FACTOR RATING: B

Type of source	Carbon monoxide		Hydrocarbons[b]		Ammonia	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Plants with methanator						
Purge gas[c]	Neg	Neg	90	45	3	1.5
Storage and loading[c]	–	–	–	–	200	100
Plants with CO absorber and regeneration system						
Regenerator exit[d]	200	100	–	–	7	3.5
Purge gas[c]	Neg	Neg	90	45	3	1.5
Storage and loading[c]	–	–	–	–	200	100

[a] References 2 and 3.

[b] Expressed as methane.

[c] Ammonia emissions can be reduced by 99 percent by passing through three stages of a packed-tower water scrubber. Hydrocarbons are not reduced.

[d] A two-stage water scrubber and incineration system can reduce these emissions to a negligible amount.

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3. Axelrod, L.C. and T.E. O'Hare. Production of Synthetic Ammonia. New York, M. W. Kellogg Company. 1964.

192

5.3 CARBON BLACK

by Charles Mann

5.3.1 Process Description

Carbon black is produced by the reaction of a hydrocarbon fuel, such as oil or gas, with a limited supply of combustion air at temperatures of 2500 to 3000°F (1370 to 1650°C). The unburned carbon is collected as an extremely fine (10- to 400-nm diameter), black, fluffy particle. The three processes for producing carbon black are the furnace process, thermal process, and channel process. In 1973 the furnace process accounted for over 90 percent of production; the thermal process, 9 percent; and the channel process, less than 1 percent. The primary use for carbon black is for strengthening rubber products (mainly rubber tires); it is also used in printing inks, surface coatings, and plastics.

5.3.1.1 Furnace Process - Furnace black is produced by combustion of hydrocarbon feed in a refractory-lined furnace. Oil-fired furnaces now predominate. In this process (Figure 5.3-1) a heavy, aromatic oil feed is preheated and fed into the furnace with about half of the air required for complete combustion and a controlled amount of natural gas. The flue gases, which contain entrained carbon particles, are cooled to about 450°F (235°C) by passage through heat exchangers and water sprays. The carbon black is then separated from the gas stream, usually by a fabric filter. A cyclone for primary collection and particle agglomeration may precede the filter. A single collection system often serves a number of furnaces that are manifolded together.

The recovered carbon black is finished to a marketable product by pulverizing and wet pelletizing to increase bulk density. Water from the wet pelletizer is driven off in an indirect-fired rotary dryer. The dried pellets are then conveyed to bulk storage. Process yields range from 35 to 65 percent, depending on the particle size of the carbon black produced and the efficiency of the process. Furnace designs and operating characteristics influence the particle size of the oil black. Generally, yields are highest for large particle blacks and lowest for small particle sizes.

The older gas-furnace process is basically the same as the oil-furnace process except that a light hydrocarbon gas is the primary feedstock and furnace designs are different. Some oil may also be added to enrich the gas feed. Yields range from 10 to 30 percent, which is much less than in the oil process, and comparatively coarser particles (40- to 80-nm diameter compared to 20- to 50-nm diameter for oil-furnace blacks) are produced. Because of the scarcity of natural gas and the comparatively low efficiency of the gas process, carbon black production by this method has been declining.

5.3.1.2 Thermal Process - The thermal process is a cyclic operation in which natural gas is thermally decomposed to carbon particles, hydrogen, methane, and a mixture of other hydrocarbons. To start the cycle, natural gas is burned to heat a brick checkerwork in the process furnace to about 3000°F (1650°C). After this temperature is reached, the air supply is cut off, the furnace stack is closed, and natural gas is introduced into the furnace. The natural gas is decomposed by the heat from the hot bricks. When the bricks become cool, the natural gas flow is shut off. The effluent gases, containing the thermal black particles, are flushed out of the furnace and cooled by water sprays to about 250°F (125°C) before passing through cyclonic collectors and fabric filters, which recover the thermal black.

The effluent gases, consisting of about 90 percent hydrogen, 6 percent methane, and a mixture of other hydrocarbons, are cooled, compressed, and used as a fuel to reheat the furnaces. Normally, more than enough hydrogen is produced to make the thermal-black process self-sustaining, and the surplus hydrogen is used to fire boilers that supply process steam and electric power.

The collected thermal black is pulverized and pelletized to a final product in much the same manner as furnace black. Thermal-process yields are generally high (35 to 60 percent), but the relatively

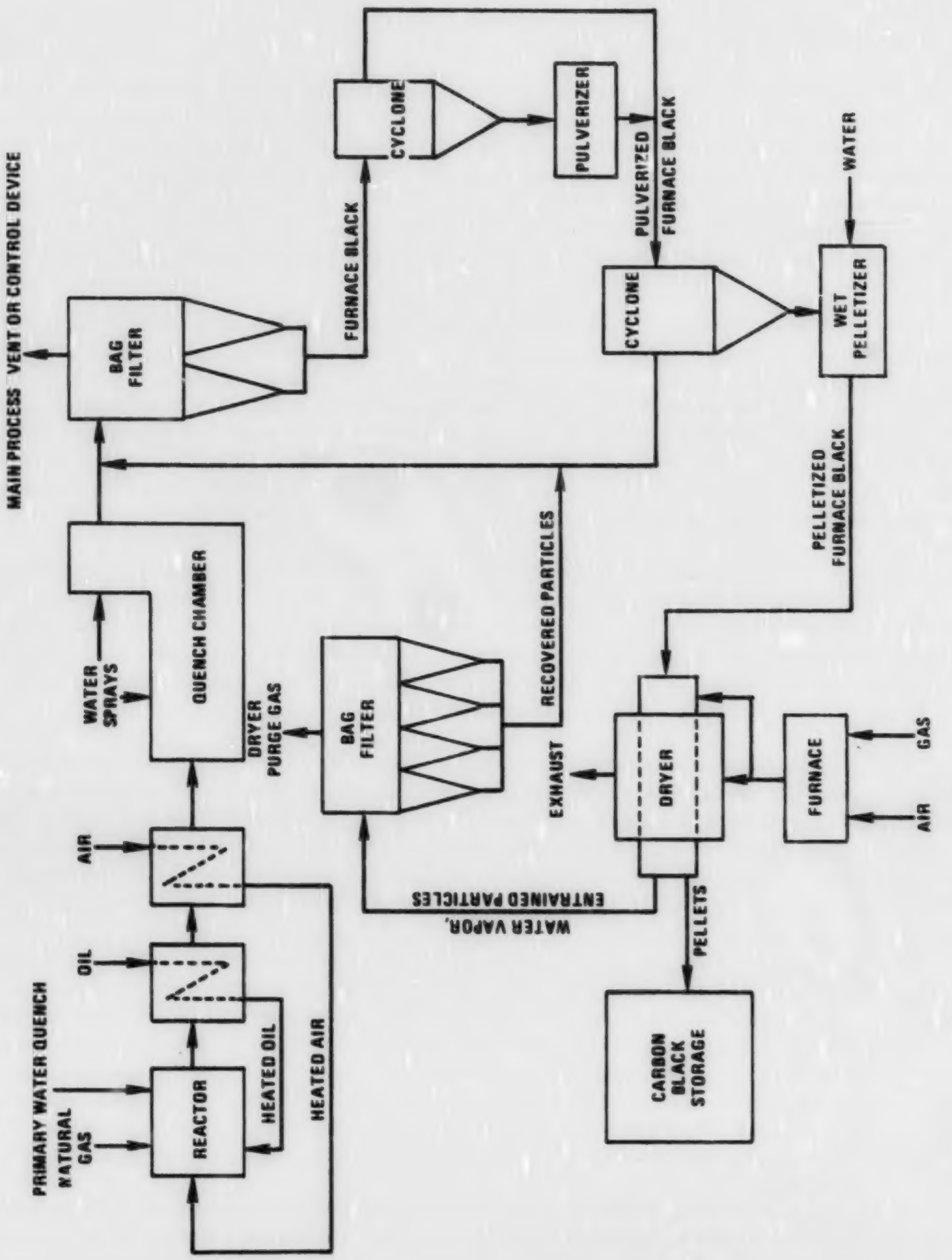

PRIMARY WATER QUENCH
NATURAL GAS
REACTOR
HEATED OIL
HEATED AIR
OIL
AIR
WATER SPRAYS
QUENCH CHAMBER
MAIN PROCESS VENT OR CONTROL DEVICE
BAG FILTER
FURNACE BLACK
CYCLONE
PULVERIZER
PULVERIZED FURNACE BLACK
CYCLONE
WET PELLETIZER
WATER
PELLETIZED FURNACE BLACK
RECOVERED PARTICLES
DRYER PURGE GAS
BAG FILTER
EXHAUST
DRYER
FURNACE
GAS
AIR
WATER VAPOR, ENTRAINED PARTICLES
PELLETS
CARBON BLACK STORAGE

Figure 5.3-1. Simplified flow diagram of carbon black production by the oil-fired furnace process.

194<

coarse particles produced (180- to 470-nm diameter) do not have the strong reinforcing properties required for rubber products.

5.3.1.3 Channel Process - In the channel-black process, natural gas is burned with a limited air supply in long, low buildings. The flame from this burning impinges on long steel channel sections that swing continuously over the flame. Carbon black deposited on the channels is scraped off into collecting hoppers. The combustion gases, containing uncollected solid carbon, carbon monoxide, and other combustion products, are then vented directly from the building. Yields from the channel-black process are only 5 percent or less, but very fine particles are produced (10- to 30-nm diameter). Channel-black production has been declining steadily from its peak in the 1940's. Since 1974 no production of channel black has been reported.

5.3.2 Emissions and Controls

Emissions from carbon black manufacture include particulates, sulfur compounds, carbon monoxide, hydrocarbons, and nitrogen oxides. Trace amounts of polynuclear organic matter (POM) are also likely to be emitted. Emissions vary considerably from one process to another. Typical emission factors are given in Table 5.3-1.

The principal source of emissions in the furnace process is the main process vent. The vent stream consists of the reactor effluent plus quench water vapor vented from the carbon-black recovery system. Gaseous emissions vary considerably according to the grade of carbon black being produced. Hydrocarbon and CO emissions tend to be higher for small-particle black production. Sulfur compound emissions are a function of the feed sulfur content. Table 5.3-1 shows the normal emission ranges to be expected from these variations in addition to typical average values. Some particulate emissions may also occur from product transport, drier vents, the bagging and storage area, and spilled and leaked materials. Such emissions are generally negligible, however, because of the high efficiency of collection devices and sealed conveying systems used to prevent product loss.

Particulate emissions from the furnace-black process are controlled by fabric filters that recover the product from process and dryer vents. Particulate emissions control is therefore proportional to the efficiency of the product recovery system. Some producers may use water scrubbers on the dryer vent system.

Gaseous emissions from the furnace process may be controlled by CO boilers, incinerators, or flares. The pellet dryer combustion furnace, which is in essence a thermal incinerator, may also be employed in a control system. CO boilers, thermal incinerators, or combinations of these devices can achieve essentially complete oxidation of CO, hydrocarbons, and reduced sulfur compounds in the process flue gas. Particulate emissions may also be reduced by combustion of some of the carbon black particles; however, emissions of sulfur dioxide and nitrogen oxides are increased by these combustion devices.

Generally, emissions from the thermal process are negligible. Small amounts of nitrogen oxides and particulates may be emitted during the heating part of the process cycle when furnace stacks are open. Entrainment of carbon particles adhering to the checker brick may occur. Nitrogen oxides may be formed since high temperatures are reached in the furnaces. During the decomposition portion of the production cycle, the process is a closed system and no emissions would occur except through leaks.

Considerable emissions result from the channel process because of low efficiency of the process and the venting of the exhaust gas directly to the atmosphere. Most of the carbon input to the process is lost as CO, CO_2, hydrocarbons, and particulate.

Table 5.3-1. EMISSION FACTORS FOR CARBON BLACK MANUFACTURE[a]
EMISSION FACTOR RATING: B (OIL FURNACE PROCESS)
C (GAS FURNACE, CHANNEL, THERMAL PROCESSES)

Process	Particulate		Carbon monoxide		Hydrocarbons[b]		Nitrogen oxides		Hydrogen sulfide[c]		Sulfur oxides[c]	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Oil furnace process[d]												
Uncontrolled	6(2-16)[e]	3(1-8)[e]	2600(1400-3300)	1300(700-1650)	200(60-520)	100(30-260)	0.4	0.2	20S(10S-26S)	10S(5S-13S)	Neg	Neg
With CO boiler	3	1.5	10[f]	5[f]	3	1.5	6	3	0.2S	0.1S	40S	20S
With flare	3	1.5	130[g]	65[g]	10	5	6	3	0.2S	0.1S	40S	20S
Gas furnace process[h]	10	5	5300(4200-6400)	2650(2100-3200)	1,800	900			Neg	Neg	Neg	Neg
Channel process[i]	2,300	1,150	33,500	16,750	11,500	5,750			Neg	Neg	Neg	Neg
Thermal process[j]	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg

[a] Expressed in terms of pounds per ton and kilograms per metric ton of carbon black product.

[b] As methane. Actual composition of emissions is 50-75% acetylene and the remainder methane.

[c] S is the weight percent sulfur in the feed. Emission factor based on a 50% yield of carbon in the feed to carbon black product and an average 50% conversion of sulfur in the feed to H_2S.

[d] References 5 and 6.

[e] Based on fabric filter collection efficiency of 99.5 to 99.9%.

[f] Based on over 99% control of CO. Thermal incinerators could also be expected to achieve 99% oxidation of CO. (Reference 6).

[g] Based on 95% oxidation of CO (Reference 6).

[h] References 1 and 2.

[i] References 1 and 2.

[j] Emissions data are not available, but no significant emissions are believed to occur.

References for Section 5.3

1. Air Pollutant Emission Factors. Final Report. Resources Research, Incorporated. Reston, Virginia. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.

2. Drogin, I. Carbon Black. J. Air Pol. Control Assoc. 18:216-228, April 1968.

3. Cox, J.T. High Quality, High Yield Carbon Black. Chem. Eng. 57:116-117, June 1950.

4. Reinke, R.A. and T.A. Ruble. Oil Black. Ind. Eng. Chem. 44:685-694, April 1952.

5. Engineering and Cost Study of Air Pollution Control for the Petrochemical Industry, Volume 1: Carbon Black Manufacture by the Furnace Process. Houdry Division, Air Products and Chemicals, Incorporated. Publication Number EPA-450/3-73-006a. June 1974.

6. Hustvedt, Kent C., Leslie B. Evans, and William M. Vatavuk. Standards Support and Environmental Impact Statement, An Investigation of the Best Systems of Emission Reduction for Furnace Process Carbon Black Plants in the Carbon Black Industry. U.S. Environmental Protection Agency, Research Triangle Park, N.C. April 1976.

7. Carbon Black (Oil Black). Continental Carbon Company. Hydrocarbon Processing. 52:111. November 1973.

5.4 CHARCOAL

5.4.1 Process Description[1]

Charcoal is generally manufactured by means of pyrolysis, or destructive distillation, of wood waste from members of the deciduous hardwood species. In this process, the wood is placed in a retort where it is externally heated for about 20 hours at 500 to 700°F (260 to 370°C). Although the retort has air intakes at the bottom, these are only used during start-up and thereafter are closed. The entire distillation cycle takes approximately 24 hours, the last 4 hours being an exothermic reaction. Four units of hardwood are required to produce one unit of charcoal.

5.4.2 Emissions and Controls[1]

In the pyrolysis of wood, all the gases, tars, oils, acids, and water are driven off, leaving virtually pure carbon. All of these except the gas, which contains methane, carbon monoxide, carbon dioxide, nitrogen oxides, and aldehydes, are useful by-products if recovered. Unfortunately, economics has rendered the recovery of the distillate by-products unprofitable, and they are generally permitted to be discharged to the atmosphere. If a recovery plant is utilized, the gas is passed through water-cooled condensers. The condensate is then refined while the remaining cool, noncondensable gas is discharged to the atmosphere. Gaseous emissions can be controlled by means of an afterburner because the unrecovered by-products are combustible. If the afterburner operates efficiently, no organic pollutants should escape into the atmosphere. Emission factors for the manufacture of charcoal are shown in Table 5.4-1.

Table 5.4-1. EMISSION FACTORS FOR CHARCOAL MANUFACTURING[a,d]
EMISSION FACTOR RATING: C

	Type of operation			
	With chemical recovery plant		Without chemical recovery plant	
Pollutant	lb/ton	kg/MT	lb/ton	kg/MT
Particulate (tar, oil)	–	–	400	200
Carbon monoxide	320[b]	160[b]	320[b]	160[b]
Hydrocarbons[c]	100[b]	50[b]	100[b]	50[b]
Crude methanol	–	–	152	76
Acetic acid	–	–	232	116
Other gases (HCHO, N_2 NO)	60	30	60[b]	30[b]

[a] Calculated values based on data in Reference 2.
[b] Emissions are negligible if afterburner is used.
[c] Expressed as methane.
[d] Emission factors expressed in units of tons of charcoal produced.

References for Section 5.4

1. Air Pollutant Emission Factors. Final Report. Resources Research, Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.

2. Shreve, R.N. Chemical Process Industries, 3rd Ed. New York, McGraw-Hill Book Company. 1967. p. 619.

5.5 CHLOR–ALKALI

5.5.1 Process Description[1]

Chlorine and caustic are produced concurrently by the electrolysis of brine in either the diaphragm or mercury cell. In the diaphragm cell, hydrogen is liberated at the cathode and a diaphragm is used to prevent contact of the chlorine produced at the anode with either the alkali hydroxide formed or the hydrogen. In the mercury cell, liquid mercury is used as the cathode and forms an amalgam with the alkali metal. The amalgam is removed from the cell and is allowed to react with water in a separate chamber, called a denuder, to form the alkali hydroxide and hydrogen.

Chlorine gas leaving the cells is saturated with water vapor and then cooled to condense some of the water. The gas is further dried by direct contact with strong sulfuric acid. The dry chlorine gas is then compressed for in-plant use or is cooled further by refrigeration to liquefy the chlorine.

Caustic as produced in a diaphragm-cell plant leaves the cell as a dilute solution along with unreacted brine. The solution is evaporated to increase the concentration to a range of 50 to 73 percent; evaporation also precipitates most of the residual salt, which is then removed by filtration. In mercury-cell plants, high-purity caustic can be produced in any desired strength and needs no concentration.

5.5.2 Emissions and Controls[1]

Emissions from diaphragm- and mercury-cell chlorine plants include chlorine gas, carbon dioxide, carbon monoxide, and hydrogen. Gaseous chlorine is present in the blow gas from liquefaction, from vents in tank cars and tank containers during loading and unloading, and from storage tanks and process transfer tanks. Other emissions include mercury vapor from mercury cathode cells and chlorine from compressor seals, header seals, and the air blowing of depleted brine in mercury-cell plants.

Chlorine emissions from chlor-alkali plants may be controlled by one of three general methods: (1) use of the gas in other plant processes, (2) neutralization in alkaline scrubbers, and (3) recovery of chlorine from effluent gas streams. The effect of specific control practices is shown to some extent in the table on emission factors (Table 5.5-1).

References for Section 5.5

1. Atmospheric Emissions from Chlor-Alkali Manufacture. U.S. EPA, Air Pollution Control Office. Research Triangle Park, N.C. Publication Number AP-80. January 1971.

2. Duprey, R.L. Compilation of Air Pollutant Emission Factors. U.S. DHEW, PHS, National Center for Air Pollution Control. Durham, N.C. PHS Publication Number 999-AP-42. 1968. p. 49.

Table 5.5-1. EMISSION FACTORS FOR CHLOR-ALKALI PLANTS[a]
EMISSION FACTOR RATING: B

Type of source	Chlorine gas	
	lb/100 tons	kg/100 MT
Liquefaction blow gases		
Diaphragm cell, uncontrolled	2,000 to 10,000	1,000 to 5,000
Mercury cell[b], uncontrolled	4,000 to 16,000	2,000 to 8,000
Water absorber	25 to 1,000	12.5 to 500
Caustic or lime scrubber	1	0.5
Loading of chlorine		
Tank car vents	450	225
Storage tank vents	1,200	600
Air-blowing of mercury-cell brine	500	250

[a] References 1 and 2.

[b] Mercury cells lose about 1.5 pounds mercury per 100 tons (0.75 kg/100 MT) of chlorine liquefied.

5.6 EXPLOSIVES

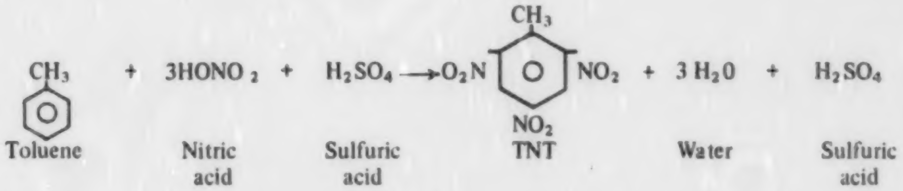
by Charles Mann

5.6.1 General[1]

An explosive is a material that, under the influence of thermal or mechanical shock, decomposes rapidly and spontaneously with the evolution of large amounts of heat and gas. Explosives fall into two major categories: high explosives and low explosives. High explosives are further subdivided into initiating or primary high explosives and secondary high explosives. Initiating high explosives are very sensitive and are generally used in small quantities in detonators and percussion caps to set off larger quantities of secondary high explosives. Secondary high explosives, chiefly nitrates, nitro compounds, and nitramines, are much less sensitive to mechanical or thermal shock, but explode with great violence when set off by an initiating explosive. The chief secondary high explosives manufactured for commercial and military use are ammonium nitrate blasting agents and 2.4. 6,-trinitrotoluene (TNT). Low explosives, such as black powder and nitrocellulose, undergo relatively slow autocombustion when set off and evolve large volumes of gas in a definite and controllable manner. A multitude of different types of explosives are manufactured. As examples of the production of a high explosive and a low explosive, the production of TNT and nitrocellulose are discussed in this section.

5.6.2 TNT Production [1-3]

TNT may be prepared by either a continuous process or a batch, three-stage nitration process using toluene, nitric acid, and sulfuric acid as raw materials. In the batch process, a mixture of oleum (fuming sulfuric acid) and nitric acid that has been concentrated to a 97 percent solution is used as the nitrating agent. The overall reaction may be expressed as:



(1)

Spent acid from the nitration vessels is fortified with make-up 60 percent nitric acid before entering the next nitrator. Fumes from the nitration vessels are collected and removed from the exhaust by an oxidation-absorption system. Spent acid from the primary nitrator is sent to the acid recovery system in which the sulfuric and nitric acid are separated. The nitric acid is recovered as a 60 percent solution, which is used for refortification of spent acid from the second and third nitrators. Sulfuric acid is concentrated in a drum concentrator by boiling water out of the dilute acid. The product from the third nitration vessel is sent to the wash house at which point asymmetrical isomers and incompletely nitrated compounds are removed by washing with a solution of sodium sulfite and sodium hydrogen sulfite (Sellite). The wash waste (commonly called red water) from the purification process is discharged directly as a liquid waste stream, is collected and sold, or is concentrated to a slurry and incinerated in rotary kilns. The purified TNT is solidified, granulated, and moved to the packing house for shipment or storage. A schematic diagram of TNT production by the batch process is shown in Figure 5.6-1.

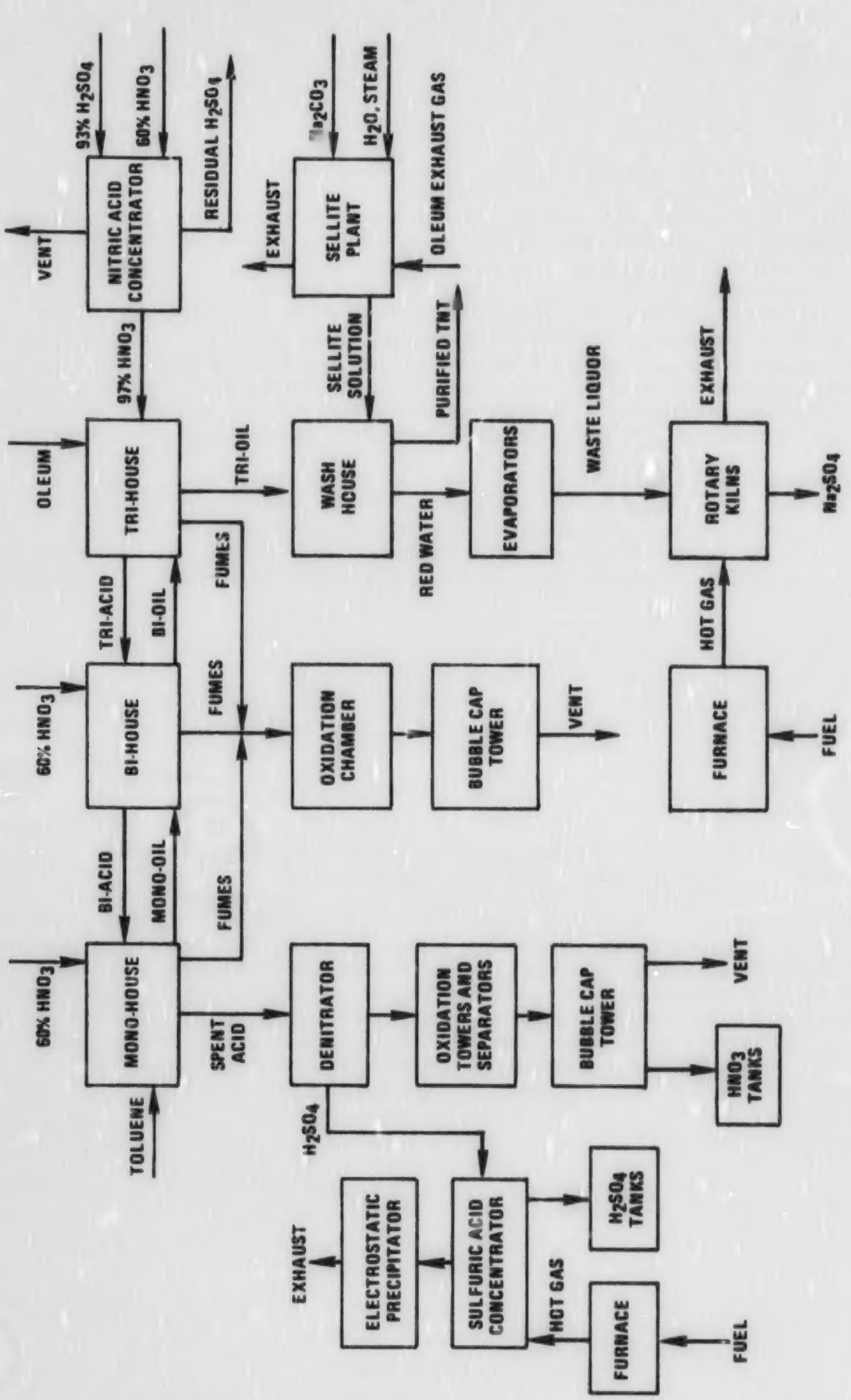

93% H_2SO_4
60% HNO_3
RESIDUAL H_2SO_4
VENT
NITRIC ACID CONCENTRATOR
97% HNO_3
OLEUM
TRI-HOUSE
TRI-ACID
BI-OIL
60% HNO_3
BI-HOUSE
BI-ACID
MONO-OIL
60% HNO_3
MONO-HOUSE
TOLUENE
FUMES
FUMES
FUMES
SPENT ACID
TRI-OIL
Na_2CO_3
H_2O, STEAM
EXHAUST
SELLITE PLANT
OLEUM EXHAUST GAS
SELLITE SOLUTION
PURIFIED TNT
WASH HOUSE
RED WATER
OXIDATION CHAMBER
BUBBLE CAP TOWER
VENT
DENITRATOR
OXIDATION TOWERS AND SEPARATORS
BUBBLE CAP TOWER
VENT
HNO_3 TANKS
H_2SO_4
EXHAUST
ELECTROSTATIC PRECIPITATOR
SULFURIC ACID CONCENTRATOR
H_2SO_4 TANKS
HOT GAS
FURNACE
FUEL
EVAPORATORS
WASTE LIQUOR
ROTARY KILNS
EXHAUST
Na_2SO_4
HOT GAS
FURNACE
FUEL

Figure 5.6-1. Flow diagram of typical batch process TNT plant.

5.6.3 Nitrocellulose Production [1]

Nitrocellulose is prepared by the batch-type "mechanical dipper" process. Cellulose, in the form of cotton linters, fibers, or specially prepared wood pulp, is purified, bleached, dried, and sent to a reactor (niter pot) containing a mixture of concentrated nitric acid and a dehydrating agent such as sulfuric acid, phosphoric acid, or magnesium nitrate. The overall reaction may be expressed as:

$$\underset{\text{Cellulose}}{C_6H_7O_2(OH)_3} + \underset{\text{Nitric acid}}{3HONO_2} + \underset{\text{Sulfuric acid}}{H_2SO_4} \longrightarrow \underset{\text{Nitrocellulose}}{C_6H_7O_2(ONO_2)_3} + \underset{\text{Water}}{3\,H_2O} + \underset{\text{Sulfuric acid}}{H_2SO_4} \qquad (2)$$

When nitration is complete, the reaction mixtures are centrifuged to remove most of the spent acid. The spent acid is fortified and reused or otherwise disposed of. The centrifuged nitrocellulose undergoes a series of water washings and boiling treatments for purification of the final product.

5.6.4 Emissions and Controls[2,3,5]

The major emissions from the manufacture of explosives are nitrogen oxides and acid mists, but smaller amounts of sulfuric oxides and particulates may also be emitted. Emissions of nitrobodies (nitrated organic compounds) may also occur from many of the TNT process units. These compounds cause objectionable odor problems and act to increase the concentration of acid mists. Emissions of sulfur oxides and nitrogen oxides from the production of nitric acid and sulfuric acid used for explosives manufacturing can be considerable. It is imperative to identify all processes that may take place at an explosives plant in order to account for all sources of emissions. Emissions from the manufacture of nitric and sulfuric acid are discussed in other sections of this publication.

In the manufacture of TNT, vents from the fume recovery system, sulfuric acid concentrators, and nitric acid concentrators are the principal sources of emissions. If open burning or incineration of waste explosives is practiced, considerable emissions may result. Emissions may also result from the production of Sellite solution and the incineration of red water. Many plants, however, now sell the red water to the paper industry where it is of economic importance.

Principal sources of emissions from nitrocellulose manufacture are from the reactor pots and centrifuges, spent acid concentrators, and boiling tubs used for purification.

The most important factor affecting emissions from explosives manufacture is the type and efficiency of the manufacturing process. The efficiency of the acid and fume recovery systems for TNT manufacture will directly affect the atmospheric emissions. In addition, the degree to which acids are exposed to the atmosphere during the manufacturing process affects the NO_X and SO_X emissions. For nitrocellulose production, emissions are influenced by the nitrogen content and the desired quality of the final product. Operating conditions will also affect emissions. Both TNT and nitrocellulose are produced in batch processes. Consequently, the processes may never reach steady state and emission concentrations may vary considerably with time. Such fluctuations in emissions will influence the efficiency of control methods. Several measures may be taken to reduce emissions from explosives manufacturing. The effects of various control devices and process changes upon emissions, along with emission factors for explosives manufacturing, are shown in Table 5.6-1. The emission factors are all related to the amount of product produced and are appropriate for estimating long-term emissions or for evaluating plant operation at full production conditions. For short time periods or for plants with intermittent operating schedules, the emission factors in Table 5.6-1 should be used with caution, because processes not associated with the nitration step are often not in operation at the same time as the nitration reactor.

Table 5.6-1. EMISSION FACTORS FOR
EMISSION FACTOR

Type of process	Particulates		Sulfur oxides (SO_2)	
	lb/ton	kg/MT	lb/ton	kg/MT
TNT - batch process[b]				
Nitration reactors				
Fume recovery	–	–	–	–
Acid recovery	–	–	–	–
Nitric acid concentrators	–	–	–	–
Sulfuric acid concentrators[c]				
Electrostatic precipitator (exit)	–	–	14(4-40)	7(2-20)
Electrostatic precipitator with scrubber[d]	–	–	Neg.	Neg.
Red water incinerator				
Uncontrolled[e]	25(0.03-126)	12.5(0.015-63)	2(0.05-3.5)	1(0.025-1.75)
Wet scrubber[f]	1	0.5	2(0.05-3.5)	1(0.025-1.75)
Sellite exhaust	–	–	59(0.01-177)	29.5(0.005-88)
TNT - continuous process[g]				
Nitration reactors				
Fume recovery	–	–	–	–
Acid recovery	–	–	–	–
Red water incinerator	0.25(0.03-0.05)	0.13(0.015-0.025)	0.24(0.05-0.43)	0.12(0.025-0.22)
Nitrocellulose[g]				
Nitration reactors[h]	–	–	1.4(0.8-2)	0.7(0.4-1)
Nitric acid concentrator	–	–	–	–
Sulfuric acid concentrator	–	–	68(0.4-135)	34(0.2-67)
Boiling tubs	–	–	–	–

[a] For some processes considerable variations in emissions have been reported. The average of the values reported is shown first, with the ranges given in parentheses. Where only one number is given, only one source test was available.

[b] Reference 5.

[c] Acid mist emissions influenced by nitrobody levels and type of fuel used in furnace.

[d] No data available for NO_x emissions after the scrubber. It is assumed that NO_x emissions are unaffected by the scrubber.

EXPLOSIVES MANUFACTURING[a]
RATING: C

Nitrogen oxides (NO_2)		Nitric acid mist (100% HNO_3)		Sulfuric acid mist (100% H_2SO_4)	
lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
25(6-38)	12.5(3-19)	1(0.3-1.9)	0.5(0.5-0.95)	–	–
55(1-136)	27.5(0.5-68)	92(0.01-275)	46(0.005-137)	–	–
37(16-72)	18.5(8-36)	–	–	9(0.3-27)	4.5(0.15-13.5)
40(2-80)	20(1-40)	–	–	65(1-188)	32.5(0.5-94)
40(2-80)	20(1-40)	–	–	5(4-6)	2.5(2-3)
26(1.5-101)	13(0.75-50)	–	–	–	–
5	2.5	–	–	–	–
–	–	–	–	6(0.6-16)	3(0.3-8)
8(6.7-10)	4(3.35-5)	1(0.3-1.9)	0.5(0.15-0.95)	–	–
3(1-4.5)	1.5(0.5-2.25)	0.02(0.01-0.03)	0.01(0.005-0.015)	–	–
7(6.1-8.4)	3.5(3-4.2)	–	–	–	–
14(3.7-34)	7(1.85-17)	19(0.5-36)	9.5(0.25-18)	–	–
14(10-18)	7(5-9)	–	–	–	–
		–	–	0.3	0.3
2	1	–	–	–	–

[e] Use low end of range for modern, efficient units and high end of range for older, less efficient units.

[f] Apparent reductions in NO_x and particulate after control may not be significant because these values are based on only one test result.

[g] Reference 4.

[h] For product with low nitrogen content (12 percent), use high end of range. For products with higher nitrogen content, use lower end of range.

References for Section 5.6

1. Shreve, R.N. Chemical Process Industries, 3rd Ed. New York, McGraw-Hill Book Company, 1967. p. 383-395.
2. Unpublished data on emissions from explosives manufacturing, National Air Pollution Control Administration, Office of Criteria and Standards, Durham, N.C. June 1970.
3. Higgins, F.B., Jr., et al. Control of Air Pollution From TNT Manufacturing. (Presented at 60th annual meeting of Air Pollution Control Association. Cleveland. June 1967. Paper 67-111.)
4. Air Pollution Engineering Source Sampling Surveys, Radford Army Ammunition Plant. U.S. Army Environmental Hygiene Agency, Edgewood Arsenal, Md.
5. Air Pollution Engineering Source Sampling Surveys, Volunteer Army Ammunition Plant and Joliet Army Ammunition Plant. U.S. Army Environmental Hygiene Agency, Edgewood Arsenal, Md.

5.7 HYDROCHLORIC ACID

Hydrochloric acid is manufactured by a number of different chemical processes. Approximately 80 percent of the hydrochloric acid, however, is produced by the by-product hydrogen chloride process, which will be the only process discussed in this section. The synthesis process and the Mannheim process are of secondary importance.

5.7.1 Process Description[1]

By-product hydrogen chloride is produced when chlorine is added to an organic compound such as benzene, toluene, and vinyl chloride. Hydrochloric acid is produced as a by-product of this reaction. An example of a process that generates hydrochloric acid as a by-product is the direct chlorination of benzene. In this process benzene, chlorine, hydrogen, air, and some trace catalysts are the raw materials that produce chlorobenzene. The gases from the reaction of benzene and chlorine consist of hydrogen chloride, benzene, chlorobenzenes, and air. These gases are first scrubbed in a packed tower with a chilled mixture of monochlorobenzene and dichlorobenzene to condense and recover any benzene or chlorobenzene. The hydrogen chloride is then absorbed in a falling film absorption plant.

5.7.2 Emissions

The recovery of the hydrogen chloride from the chlorination of an organic compound is the major source of hydrogen chloride emissions. The exit gas from the absorption or scrubbing system is the actual source of the hydrogen chloride emitted. Emission factors for hydrochloric acid produced as by-product hydrogen chloride are presented in Table 5.7-1.

Table 5.7-1. EMISSION FACTORS FOR HYDROCHLORIC ACID MANUFACTURING[a]
EMISSION FACTOR RATING: B

Type of process	Hydrogen chloride emissions	
	lb/ton	kg/MT
By-product hydrogen chloride		
With final scrubber	0.2	0.1
Without final scrubber	3	1.5

[a] Reference 1.

Reference for Section 5.7

1. Atmospheric Emissions from Hydrochloric Acid Manufacturing Processes. U.S. DHEW, PHS, CPEHS, National Air Pollution Control Administration. Durham, N.C. Publication Number AP-54. September 1969.

5.8 HYDROFLUORIC ACID

5.8.1 Process Description[1]

All hydrofluoric acid in the United States is currently produced by the reaction of acid-grade fluorspar with sulfuric acid for 30 to 60 minutes in externally fired rotary kilns at a temperature of 400° to 500°F (204° to 260°C).[2,3,4] The resulting gas is then cleaned, cooled, and absorbed in water and weak hydrofluoric acid to form a strong acid solution. Anhydrous hydrofluoric acid is formed by distilling 80 percent hydrofluoric acid and condensing the gaseous HF which is driven off.

5.8.2 Emissions and Controls[1]

Air pollutant emissions are minimized by the scrubbing and absorption systems used to purify and recover the HF. The initial scrubber utilizes concentrated sulfuric acid as a scrubbing medium and is designed to remove dust, SO_2, SO_3, sulfuric acid mist, and water vapor present in the gas stream leaving the primary dust collector. The exit gases from the final absorber contain small amounts of HF, silicon tetrafluoride (SiF_4), CO_2, and SO_2 and may be scrubbed with a caustic solution to reduce emissions further. A final water ejector, sometimes used to draw the gases through the absorption system, will reduce fluoride emissions. Dust emissions may also result from raw fluorspar grinding and drying operations. Table 5.8-1 lists the emission factors for the various operations.

Table 5.8-1. EMISSION FACTORS FOR HYDROFLUORIC ACID MANUFACTURING[a]
EMISSION FACTOR RATING: C

Type of operation	Fluorides		Particulates	
	lb/ton acid	kg/MT acid	lb/ton fluorspar	kg/MT fluorspar
Rotary kiln				
Uncontrolled	50	25	–	–
Water scrubber	0.2	0.1	–	--
Grinding and drying of fluorspar	–	–	20[b]	10[b]

[a] References 2 and 5.

[b] Factor given for well-controlled plant.

References for Section 5.8

1. Air Pollutant Emission Factors. Final Report. Resources Research Inc., Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.

2. Rogers, W.E. and K. Muller. Hydrofluoric Acid Manufacture. Chem. Eng. Progr. 59:85-88, May 1963.

3. Heller, A.N., S.T. Cuffe, and D.R. Goodwin. Inorganic Chemical Industry. In: Air Pollution Engineering Manual. Danielson, J.A. (ed.). U.S. DHEW, PHS. National Center for Air Pollution Control. Cincinnati, Ohio. Publication Number 999-AP-40. 1967. p. 197-198.

4. Hydrofluoric Acid. Kirk-Othmer Encyclopedia of Chemical Technology. Vol. 9. New York. John Wiley and Sons, Inc. 1964. p. 444-485.

5. Private Communication between Resources Research, Incorporated, and E.I. DuPont de Nemours and Company. Wilmington, Delaware. January 13, 1970.

5.9 NITRIC ACID

Revised by William Vatavuk

5.9.1 Process Description

5.9.1.1 Weak Acid Production[1] - Nearly all the nitric acid produced in the United States is manufactured by the high-pressure catalytic oxidation of ammonia (Figure 5.9-1). Typically, this process consists of three steps, each of which corresponds to a distinct chemical reaction. First, a 1:9 ammonia-air mixture is oxidized at high temperature and pressure (6.4 to 9.2 atmospheres), as it passes through a platinum-rhodium catalyst, according to the reaction:

$$\underset{\text{Ammonia}}{4NH_3} + \underset{\text{Oxygen}}{5O_2} \rightarrow \underset{\text{Nitric oxide}}{4NO} + \underset{\text{Water}}{6H_2O} \qquad (1)$$

After the process stream is cooled to 100°F (38°C) or less by passage through a cooler-condenser, the nitric oxide reacts with residual oxygen:

$$2NO + O_2 \rightarrow \underset{\text{Nitrogen dioxide}}{2NO_2} \rightleftharpoons \underset{\text{Nitrogen tetroxide}}{N_2O_4} \qquad (2)$$

Finally, the gases are introduced into a bubble-cap plate absorption column where they are contacted with a countercurrent stream of water. The exothermic reaction that occurs is:

$$3NO_2 + H_2O \rightarrow \underset{\substack{\text{Nitric acid} \\ \text{50 to 70\% aqueous}}}{2HNO_3} + NO \qquad (3)$$

The production of nitric oxide in reaction (3) necessitates the introduction of a secondary air stream into the column to effect its oxidation to nitrogen dioxide, thereby perpetuating the absorption operation.

The spent gas flows from the top of the absorption tower to an entrainment separator for acid mist removal, through the ammonia oxidation unit for energy absorption from the ammonia stream, through an expander for energy recovery, and finally to the stack. In most plants the stack gas is treated before release to the atmosphere by passage through either a catalytic combustor or, less frequently, an alkaline scrubber.

5.9.1.2 High-Strength Acid Production[1] - To meet requirements for high strength acid, the 50 to 70 percent acid produced by the pressure process is concentrated to 95 to 99 percent at approximately atmospheric pressure. The concentration process consists of feeding strong sulfuric acid and 60 percent nitric acid to the top of a packed column where it is contacted by an ascending stream of weak acid vapor, resulting in the dehydration of the latter. The concentrated acid vapor that leaves the column passes to a bleacher and countercurrent condense system to effect condensation of the vapors and separation of the small amounts of nitric oxides and oxygen th form as dehydration by-products. These by-products then flow to an absorption column where the nitric oxi mixes with auxiliary air to form nitrogen dioxide, which is, in turn, recovered as weak nitric acid. Finally, unreacted gases are vented to the atmosphere from the top of the column.

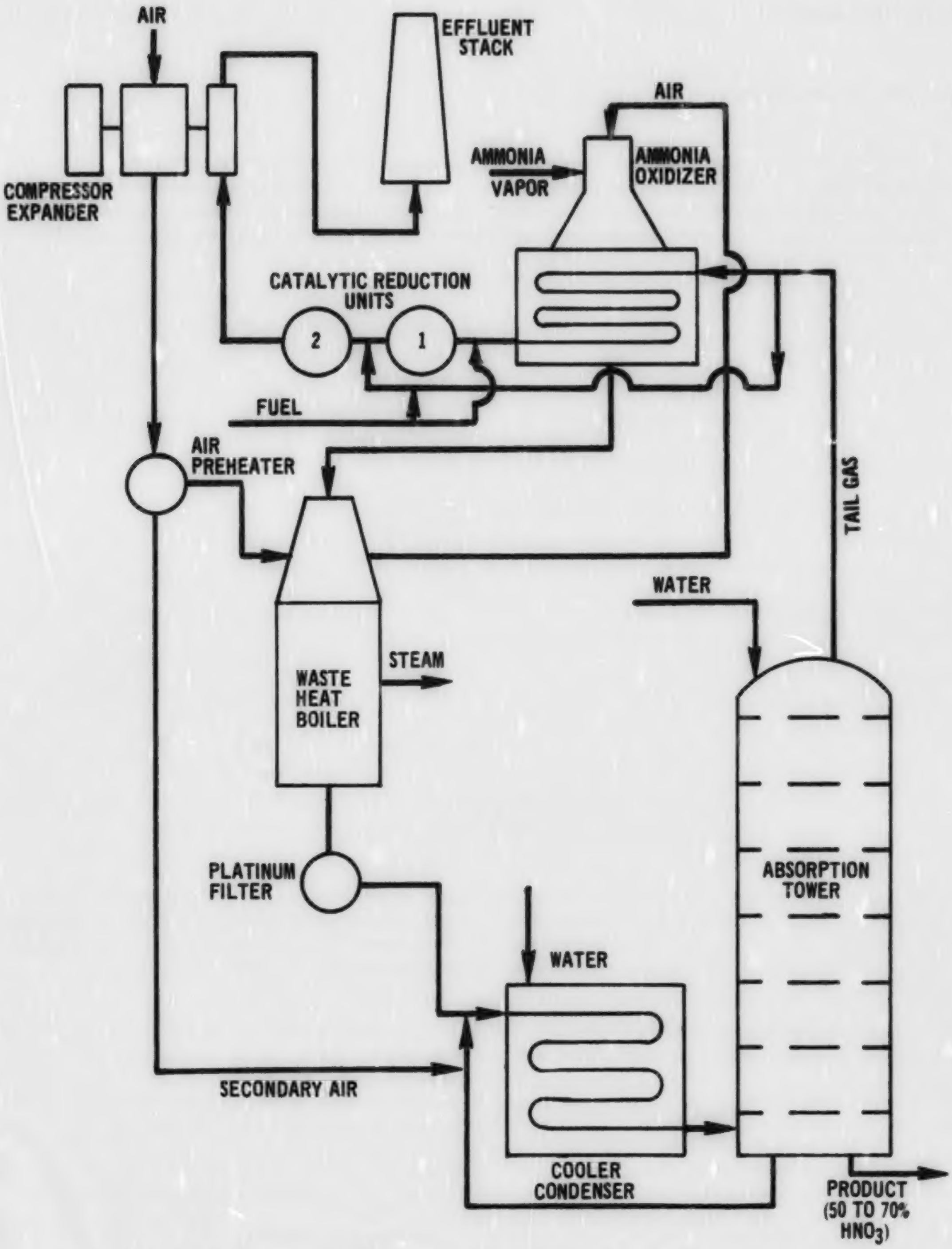

AIR
EFFLUENT STACK
COMPRESSOR EXPANDER
AIR
AMMONIA VAPOR
AMMONIA OXIDIZER
CATALYTIC REDUCTION UNITS
2
1
FUEL
AIR PREHEATER
TAIL GAS
WATER
STEAM
WASTE HEAT BOILER
PLATINUM FILTER
ABSORPTION TOWER
WATER
SECONDARY AIR
COOLER CONDENSER
PRODUCT (50 TO 70% HNO_3)

Figure 5.9-1. Flow diagram of typical nitric acid plant using pressure process.

5.9.2 Emissions and Controls[1-3]

The emissions derived from nitric acid manufacture consist primarily of nitric oxide, which accounts for visible emissions; nitrogen dioxide; and trace amounts of nitric acid mist. By far, the major source of nitrogen oxides is the tail gas from the acid absorption tower (Table 5.9-1). In general, the quantity of NO_x emissions is directly related to the kinetics of the nitric acid formation reaction.

The specific operating variables that increase tail gas NO_x emissions are: (1) insufficient air supply, which results in incomplete oxidation of NO; (2) low pressure in the absorber; (3) high temperature in the cooler-condenser and absorber; (4) production of an excessively high-strength acid; and (5) operation at high throughput rates, which results in decreased residence time in the absorber.

Aside from the adjustment of these variables, the most commonly used means for controlling emissions is the catalytic combustor. In this device, tail gases are heated to ignition temperature, mixed with fuel (natural gas, hydrogen, or a mixture of both), and passed over a catalyst. The reactions that occur result in the successive reduction of NO_2 to NO and, then, NO to N_2. The extent of reduction of NO_2 to N_2 in the combustor is, in turn, a function of plant design, type of fuel used, combustion temperature and pressure, space velocity through the combustor, type and amount of catalyst used, and reactant concentrations (Table 5.9-1).

Comparatively small amounts of nitrogen oxides are also lost from acid concentrating plants. These losses (mostly NO_2) occur from the condenser system, but the emissions are small enough to be easily controlled by the installation of inexpensive absorbers.

Table 5.9-1. NITROGEN OXIDE EMISSIONS FROM NITRIC ACID PLANTS[a]
EMISSION FACTOR RATING: B

Type of control	Control efficiency, %	Emissions (NO_2)[b]	
		lb/ton acid	kg/MT acid
Weak acid			
Uncontrolled	0	50 to 55[c]	25.0 to 27.5
Catalytic combustor (natural gas fired)	78 to 97	2 to 7[d]	1.0 to 3.5
Catalytic combustor (hydrogen fired)	97 to 99.8	0.0 to 1.5	0.0 to 0.75
Catalytic combustor (75% hydrogen, 25% natural gas fired)	98 to 98.5	0.8 to 1.1	0.4 to 0.55
High-strength acid	–	0.2 to 5.0	0.1 to 2.5

[a] References 1 and 2.

[b] Based on 100 percent acid production.

[c] Range of values taken from four plants measured at following process conditions: production rate, 120 tons (109 MT) per day (100 percent rated capacity); absorber exit temperature, 90° F (32° C); absorber exit pressure, 7.8 atmospheres; acid strength, 57 percent. Under different conditions, values can vary from 43 to 57 lb/ton (21.5 to 28.5 kg/MT).

[d] To present a more realistic picture, ranges of values were used instead of averages.

212

Acid mist emissions do not occur from a properly operated plant. The small amounts that may be present in the absorber exit gas stream are removed by a separator or collector prior to entering the catalytic combustor or expander.

Finally, small amounts of nitrogen dioxide are lost during the filling of storage tanks and tank cars.

Nitrogen oxide emissions (expressed as NO_2) are presented for weak nitric acid plants in table 5.9-1. The emission factors vary considerably with the type of control employed, as well as with process conditions. For comparison purposes, the Environmental Protection Agency (EPA) standard for both new and modified plants is 3.0 pounds per ton of 100 percent acid produced (1.5 kilograms per metric ton), maximum 2-hour average, expressed as NO_2.[4] Unless specifically indicated as 100 percent acid, production rates are generally given in terms of the total weight of product (water and acid). For example, a plant producing 500 tons (454 MT) per day of 55 weight percent nitric acid is really producing only 275 tons (250 MT) per day of 100 percent acid.

References for Section 5.9

1. Control of Air Pollution from Nitric Acid Plants. Unpublished Report. Environmental Protection Agency, Research Triangle Park, N.C.

2. Atmospheric Emissions from Nitric Acid Manufacturing Processes. U.S. DHEW, PHS, Division of Air Pollution. Cincinnati, Ohio. Publication Number 999-AP-27. 1966.

3. Unpublished emission data from a nitric acid plant. U.S. DHEW, PHS, EHS, National Air Pollution Control Administration, Office of Criteria and Standards. Durham, N.C. June 1970.

4. Standards of Performance for New Stationary Sources. Environmental Protection Agency, Washington, D.C. Federal Register. *36*(247): December 23, 1971.

5.10 PAINT AND VARNISH

5.10.1 Paint Manufacturing[1]

The manufacture of paint involves the dispersion of a colored oil or pigment in a vehicle, usually an oil or resin, followed by the addition of an organic solvent for viscosity adjustment. Only the physical processes of weighing, mixing, grinding, tinting, thinning, and packaging take place; no chemical reactions are involved.

These processes take place in large mixing tanks at approximately room temperature.

The primary factors affecting emissions from paint manufacture are care in handling dry pigments, types of solvents used, and mixing temperature.[2,3] About 1 or 2 percent of the solvents is lost even under well-controlled conditions. Particulate emissions amount to 0.5 to 1.0 percent of the pigment handled.[4]

5.10.2 Varnish Manufacturing[1-3]

The manufacture of varnish also involves the mixing and blending of various ingredients to produce a wide range of products. However, in this case chemical reactions are initiated by heating. Varnish is cooked in either open or enclosed gas-fired kettles for periods of 4 to 16 hours at temperatures of 200 to 650°F (93 to 340°C).

Varnish cooking emissions, largely in the form or organic compounds, depend on the cooking temperatures and times, the solvent used, the degree of tank enclosure, and the type of air pollution controls used. Emissions from varnish cooking range from 1 to 6 percent of the raw material.

To reduce hydrocarbons from the manufacture of paint and varnish, control techniques include condensers and/or adsorbers on solvent-handling operations, and scrubbers and afterburners on cooking operations. Emission factors for paint and varnish are shown in Table 5.10-1.

Table 5.10-1. EMISSION FACTORS FOR PAINT AND VARNISH MANUFACTURING WITHOUT CONTROL EQUIPMENT[a,b]
EMISSION FACTOR RATING: C

Type of product	Particulate		Hydrocarbons[c]	
	lb/ton pigment	kg/MT pigment	lb/ton of product	kg/MT pigment
Paint	2	1	30	15
Varnish				
Bodying oil	–	–	40	20
Oleoresinous	–	–	150	75
Alkyd	–	–	160	80
Acrylic	–	–	20	10

[a] References 2 and 4 through 8.

[b] Afterburners can reduce gaseous hydrocarbon emissions by 99 percent and particulates by about 90 percent. A water spray and oil filter system can reduce particulates by about 90 percent.[5]

[c] Expressed as undefined organic compounds whose composition depends upon the type of varnish or paint.

References for Section 5.10

1. Air Pollutant Emission Factors. Final Report. Resources Research, Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.

2. Stenburg, R.L. Atmospheric Emissions from Paint and Varnish Operations. Paint Varn. Prod. p. 61-65 and 111-114, September 1959.

3. Private Communication between Resources Research, Incorporated, and National Paint, Varnish and Lacquer Association. September 1969.

4. Unpublished engineering estimates based on plant visits in Washington, D.C. Resources Research, Incorporated. Reston, Va. October 1969.

5. Chatfield, H.E. Varnish Cookers. In: Air Pollution Engineering Manual. Danielson, J. A. (ed.). U.S. DHEW, PHS, National Center for Air Pollution Control. Cincinnati, Ohio. Publication Number 999-AP-40. 1967. p. 688-695.

6. Lunche, E.G. et al. Distribution Survey of Products Emitting Organic Vapors in Los Angeles County. Chem. Eng. Progr. *53*. August 1957.

7. Communication on emissions from paint and varnish operations with G. Sallee, Midwest Research Institute. December 17, 1969.

8. Communication with Roger Higgins, Benjamin Moore Paint Company. June 25, 1968 .

5.11 PHOSPHORIC ACID

Phosphoric acid is produced by two principal methods, the wet process and the thermal process. The wet process is usually employed when the acid is to be used for fertilizer production. Thermal-process acid is normally of higher purity and is used in the manufacture of high-grade chemical and food products.

5.11.1 Wet Process[1,2]

In the wet process, finely ground phosphate rock is fed into a reactor with sulfuric acid to form phosphoric acid and gypsum. There is usually little market for the gypsum produced, and it is handled as waste material in gypsum ponds. The phosphoric acid is separated from the gypsum and other insolubles by vacuum filtration. The acid is then normally concentrated to about 50 to 55 percent P_2O_5. When superphosphoric acid is made, the acid is concentrated to between 70 and 85 percent P_2O_5.

Emissions of gaseous fluorides, consisting mostly of silicon tetrafluoride and hydrogen fluoride, are the major problems from wet-process acid. Table 5.11-1 summarizes the emission factors from both wet-process acid and thermal-process acid.

5.11.2 Thermal Process[1]

In the thermal process, phosphate rock, siliceous flux, and coke are heated in an electric furnace to produce elemental phosphorus. The gases containing the phosphorus vapors are passed through an electrical precipitator to remove entrained dust. In the "one-step" version of the process, the gases are next mixed with air to form P_2O_5 before passing to a water scrubber to form phosphoric acid. In the "two-step" version of the process, the phosphorus is condensed and pumped to a tower in which it is burned with air, and the P_2O_5 formed is hydrated by a water spray in the lower portion of the tower.

The principal emission from thermal-process acid is P_2O_5 acid mist from the absorber tail gas. Since all plants are equipped with some type of acid-mist collection system, the emission factors presented in Table 5.11-1 are based on the listed types of control.

Table 5.11-1. EMISSION FACTORS FOR PHOSPHORIC ACID PRODUCTION
EMISSION FACTOR RATING: B

Source	Particulates		Fluorides	
	lb/ton	kg/MT	lb/ton	kg/MT
Wet process (phosphate rock)				
Reactor, uncontrolled	–	–	18[a]	9[a]
Gypsum pond	–	–	1[b]	1.1[b]
Condenser, uncontrolled	–	–	20[a]	10[a]
Thermal process (phosphorus burned[c])				
Packed tower	4.6	2.3	–	–
Venturi scrubber	5.6	2.8	–	–
Glass-fiber mist eliminator	3.0	1.5	–	–
Wire-mesh mist eliminator	2.7	1.35	–	–
High-pressure-drop mist eliminator	0.2	0.1	–	–
Electrostatic precipitator	1.8	0.9	–	–

[a] References 2 and 3.

[b] Pounds per acre per day (kg/hectare-day); approximately 0.5 acre (0.213 hectare) is required to produce 1 ton of P_2O_5 daily.

[c] Reference 4.

References for Section 5.11

1. Duprey, R.L. Compilation of Air Pollutant Emission Factors. U.S. DHEW, PHS, National Center for Air Pollution Control. Durham, N.C. PHS Publication Number 999-AP-42. 1968. p. 16.

2. Atmospheric Emissions from Wet-Process Phosphoric Acid Manufacture. U.S. DHEW, PHS, EHS, National Air Pollution Control Administration. Raleigh, N.C. Publication Number AP-57. April 1970.

3. Control Techniques for Fluoride Emissions. Internal document. U.S. EPA, Office of Air Programs. Research Triangle Park, N.C. 1970.

4. Atmospheric Emissions from Thermal-Process Phosphoric Acid Manufacturing. Cooperative Study Project: Manufacturing Chemists' Association, Incorporated, and Public Health Service. U.S. DHEW, PHS, National Air Pollution Control Administration. Durham, N.C. Publication Number AP-48. October 1968.

5.12 PHTHALIC ANHYDRIDE

by Pam Canova

5.12.1 General[1]

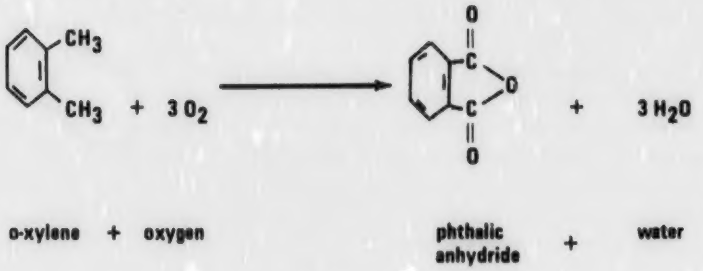
Phthalic anhydride (PAN) production in the United States in 1972 was 0.9 billion pounds per year; this total is estimated to increase to 2.2 billion pounds per year by 1985. Of the current production, 50 percent is used for plasticizers, 25 percent for alkyd resins, 20 percent for unsaturated polyester resins, and 5 percent for miscellaneous and exports. PAN is produced by catalytic oxidation of either ortho-xylene or naphthalene. Since naphthalene is a higher priced feedstock and has a lower feed utilization (about 1.0 lb PAN/lb o-xylene versus 0.97 lb PAN/lb naphthalene), future production growth is predicted to utilize o-xylene. Because emission factors are intended for future as well as present application, this report will focus mainly on PAN production utilizing o-xylene as the main feedstock.

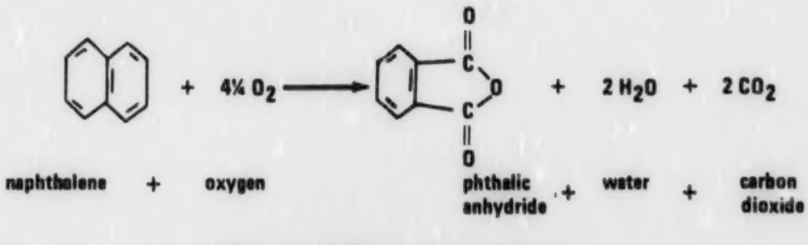
The processes for producing PAN by o-xylene or naphthalene are the same except for reactors, catalyst handling, and recovery facilities required for fluid bed reactors.

In PAN production using o-xylene as the basic feedstock, filtered air is preheated, compressed, and mixed with vaporized o-xylene and fed into the fixed-bed tubular reactors. The reactors contain the catalyst, vanadium pentoxide, and are operated at 650 to 725°F (340 to 385°C). Small amounts of sulfur dioxide are added to the reactor feed to maintain catalyst activity. Exothermic heat is removed by a molten salt bath circulated around the reactor tubes and transferred to a steam generation system.

Naphthalene-based feedstock is made up of vaporized naphthalene and compressed air. It is transferred to the fluidized bed reactor and oxidized in the presence of a catalyst, vanadium pentoxide, at 650 to 725°F (340 to 385°C). Cooling tubes located in the catalyst bed remove the exothermic heat which is used to produce high-pressure steam. The reactor effluent consists of PAN vapors, entrained catalyst, and various by-products and non-reactant gas. The catalyst is removed by filtering and returned to the reactor.

The chemical reactions for air oxidation of o-xylene and naphthalene are as follows.





The reactor effluent containing crude PAN plus products from side reactions and excess oxygen passes to a series of switch condensers where the crude PAN cools and crystallizes. The condensers are alternately cooled and then heated, allowing PAN crystals to form and then melt from the condenser tube fins.

The crude liquid is transferred to a pretreatment section in which phthalic acid is dehydrated to anhydride. Water, maleic anhydride, and benzoic acid are partially evaporated. The liquid then goes to a vacuum distillation section where pure PAN (99.8 wt. percent pure) is recovered. The product can be stored and shipped either as a liquid or a solid (in which case it is dried, flaked, and packaged in multi-wall paper bags). Tanks for holding liquid PAN are kept at 300°F (150°C) and blanketed with dry nitrogen to prevent the entry of oxygen (fire) or water vapor (hydrolysis to phthalic acid).

Maleic anhydride is currently the only by-product being recovered.

Figures 1 and 2 show the process flow for air oxidation of o-xylene and naphthalene, respectively.

5.12.2 Emissions and Controls[1]

Emissions from o-xylene and naphthalene storage are small and presently are not controlled.

The major contributor of emissions is the reactor and condenser effluent which is vented from the condenser unit. Particulate, sulfur oxides (for o-xylene-based production), and carbon monoxide make up the emissions, with carbon monoxide comprising over half the total. The most efficient (96 percent) system of control is the combined usage of a water scrubber and thermal incinerator. A thermal incinerator alone is approximately 95 percent efficient in combustion of pollutants for o-xylene-based production, and 80 percent efficient for naphthalene-based production. Thermal incinerators with steam generation show the same efficiencies as thermal incinerators alone. Scrubbers have a 99 percent efficiency in collecting particulates, but are practically ineffective in reducing carbon monoxide emissions. In naphthalene-based production, cyclones can be used to control catalyst dust emissions with 90 to 98 percent efficiency.

Pretreatment and distillation emissions—particulates and hydrocarbons—are normally processed through the water scrubber and/or incinerator used for the main process stream (reactor and condenser) or scrubbers alone, with the same efficiency percentages applying.

Product storage in the liquid phase results in small amounts of gaseous emissions. These gas streams can either be sent to the main process vent gas control devices or first processed through sublimation boxes or devices used to recover escaped PAN. Flaking and bagging emissions are negligible, but can be sent to a cyclone for recovery of PAN dust. Exhaust from the cyclone presents no problem.

Table 5.12-1 gives emission factors for controlled and uncontrolled emissions from the production of PAN.

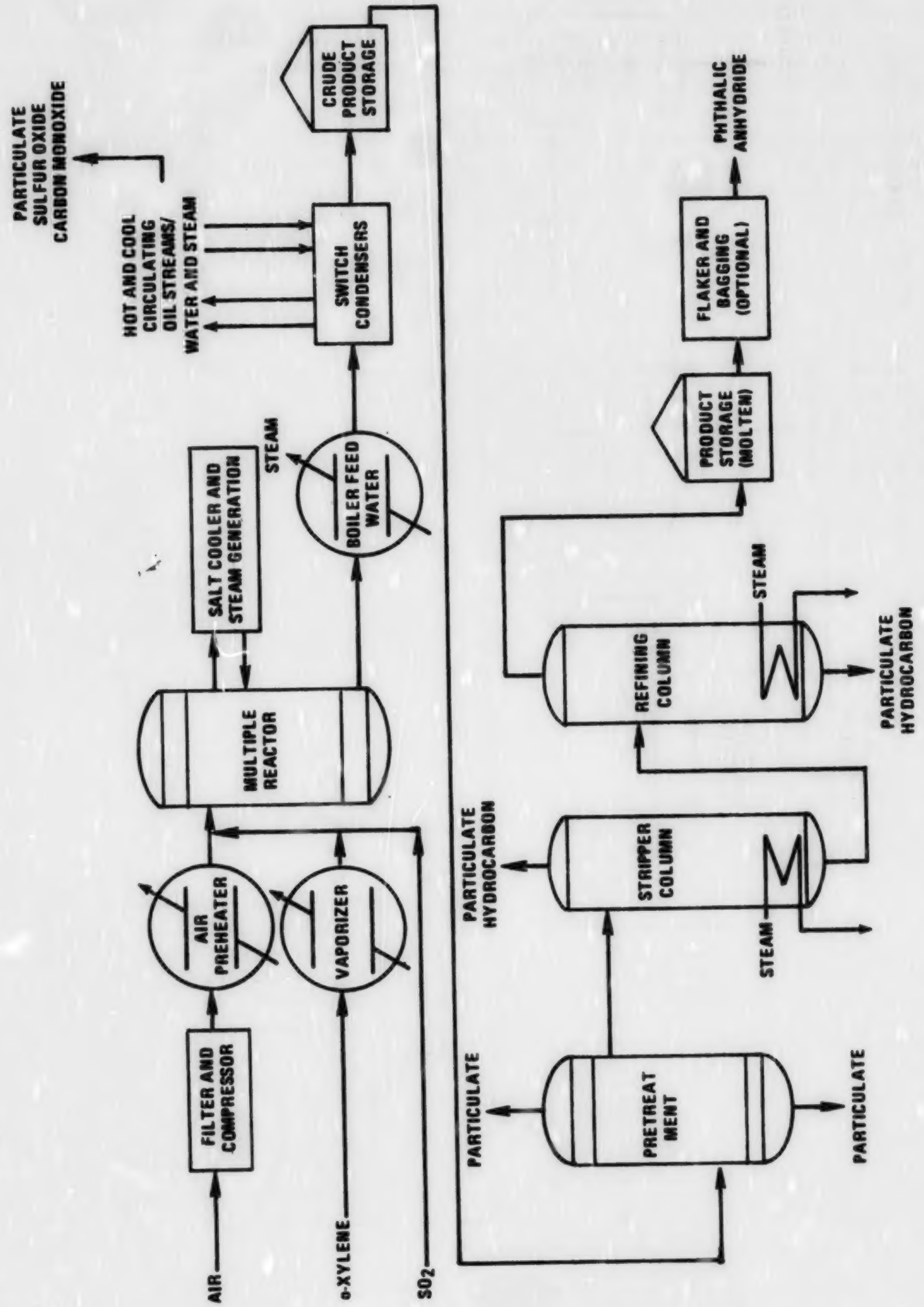

AIR
FILTER AND COMPRESSOR
AIR PREHEATER
o-XYLENE
VAPORIZER
SO_2
MULTIPLE REACTOR
SALT COOLER AND STEAM GENERATION
BOILER FEED WATER
STEAM
SWITCH CONDENSERS
HOT AND COOL CIRCULATING OIL STREAMS/ WATER AND STEAM
PARTICULATE
SULFUR OXIDE
CARBON MONOXIDE
CRUDE PRODUCT STORAGE
PARTICULATE
PRETREAT MENT
PARTICULATE
PARTICULATE
HYDROCARBON
STRIPPER COLUMN
STEAM
REFINING COLUMN
STEAM
PARTICULATE
HYDROCARBON
PRODUCT STORAGE (MOLTEN)
FLAKER AND BAGGING (OPTIONAL)
PHTHALIC ANHYDRIDE

Figure 5.12-1. Flow diagram for phthalic anhydride using o-xylene as basic feedstock.[1]

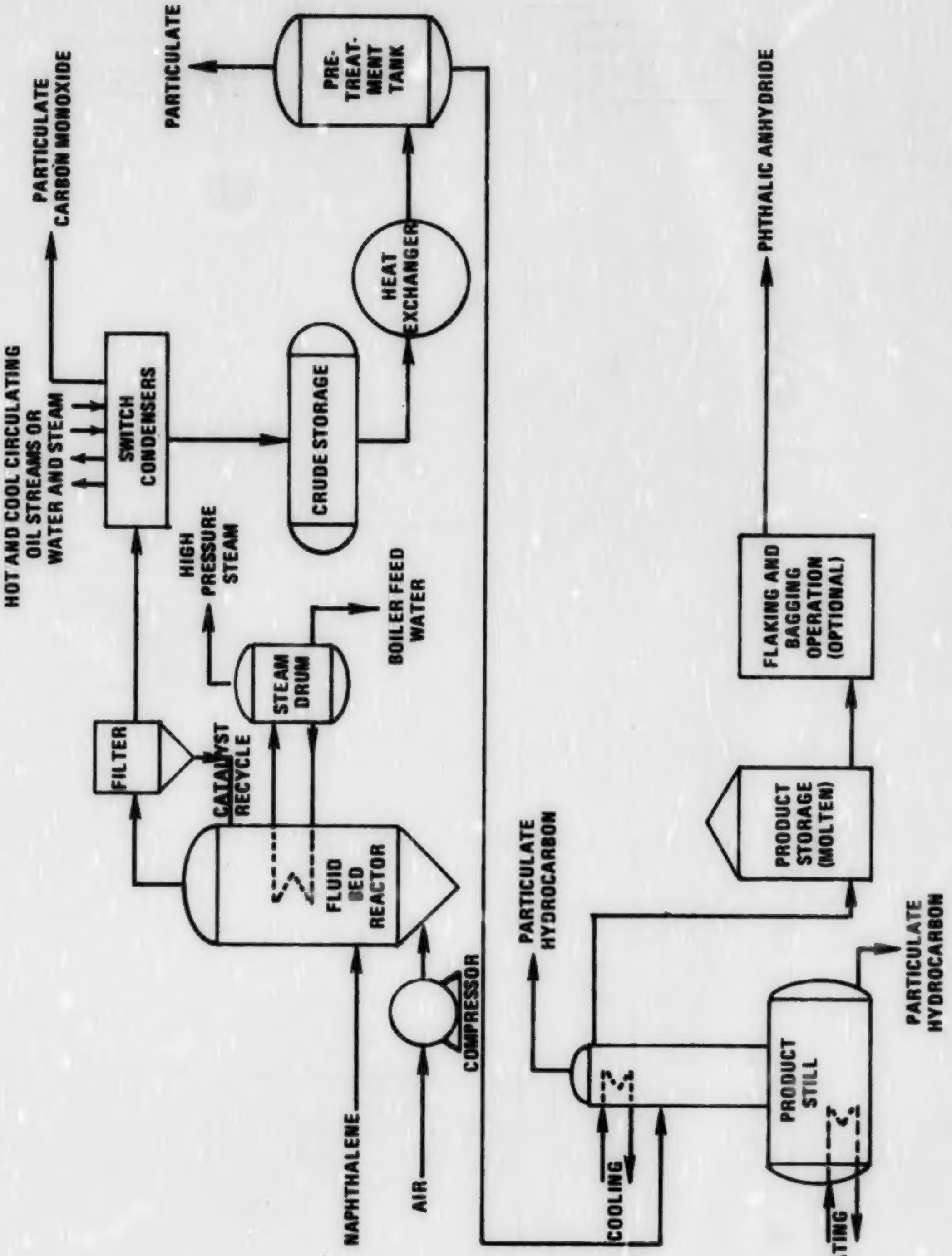

NAPHTHALENE
AIR
COMPRESSOR
FLUID BED REACTOR
CATALYST RECYCLE
FILTER
STEAM DRUM
HIGH PRESSURE STEAM
BOILER FEED WATER
SWITCH CONDENSERS
HOT AND COOL CIRCULATING OIL STREAMS OR WATER AND STEAM
PARTICULATE CARBON MONOXIDE
CRUDE STORAGE
HEAT EXCHANGER
PRE-TREAT-MENT TANK
PARTICULATE
COOLING
PARTICULATE HYDROCARBON
PRODUCT STILL
HEATING
PARTICULATE HYDROCARBON
PRODUCT STORAGE (MOLTEN)
FLAKING AND BAGGING OPERATION (OPTIONAL)
PHTHALIC ANHYDRIDE

Figure 5.12-2. Flow diagram for phthalic anhydride using naphthalene as basic feedstock.1

Table 5.12-1. EMISSION FACTORS FOR PHTHALIC ANHYDRIDE[1,a]
EMISSION FACTOR RATING: B

Process	Particulate		SO_x		HC		CO	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Oxidation of o-xylene[b]								
Main process stream[c]								
Uncontrolled	138[d]	69[d]	9.4[e]	4.7[e]	0	0	301	151
W/scrubber and thermal incinerator	6	3	9.4	4.7	0	0	12	6
W/thermal incinerator	7	4	9.4	4.7	0	0	15	8
W/incinerator with steam generator	7	4	9.4	4.7	0	0	15	8
Pretreatment								
Uncontrolled	13[f]	6.4[f]	0	0	0	0	0	0
W/scrubber and thermal incinerator	0.5	0.3	0	0	0	0	0	0
W/thermal incinerator	0.7	0.4	0	0	0	0	0	0
Distillation								
Uncontrolled	89[d]	45[d]	0	0	2.4	1.2	0	0
W/scrubber and thermal incinerator	4	2	0	0	<0.1	<0.1	0	0
W/thermal incinerator	4	2	0	0	0.1	<0.1	0	0
Oxidation of naphthalene[b]								
Main process stream[c]								
Uncontrolled	569[,i]	289[,i]	0	0	0	0	100	50
W/thermal incinerator	11	6	0	0	0	0	20	10
W/scrubber	0.6	0.3	0	0	0	0	100	50
Pretreatment								
Uncontrolled	5[h]	2.5[h]	0	0	0	0	0	0
W/thermal incinerator	1	0.5	0	0	0	0	0	0
W/scrubber	<0.1	<0.1	0	0	0	0	0	0
Distillation								
Uncontrolled	389	199	0	0	10	5	0	0
W/thermal incinerator	8	4	0	0	2	1	0	0
W/scrubber	0.4	0.2	0	0	0.1	<0.1	0	0

[a] Emission factors are in units of pounds of pollutant per ton (kilogram of pollutant per metric ton) of phthalic anhydride produced.

[b] Control devices listed are those currently being used by phthalic anhydride plants.

[c] Main process stream includes the reactor and multiple switch condensers as vented through the condenser unit.

[d] Particulate consists of phthalic anhydride, maleic anhydride, and benzoic acid.

[e] Emissions change with catalyst age. Value shown corresponds to relatively fresh catalyst. Can be 19 to 25 lb/ton (9.5 to 13 kg/MT) for aged catalyst.

[f] Particulate consists of phthalic anhydride and maleic anhydride.

[g] Particulate consists of phthalic anhydride, maleic anhydride, and naphthaquinone.

[h] Particulate is phthalic anhydride.

[i] Particulate does not include catalyst dust which is controlled by cyclones with an efficiency of 90 to 98 percent.

Reference for Section 5.12

1. Engineering and Cost Study of Air Pollution Control for the Petrochemical Industry. Vol 7: Phthalic Anhydride Manufacture from Ortho-Xylene. Houdry Division, Air Products and Chemicals, Inc., Marcus Hook, Pa. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. Publication No. EPA-450/3-73-006-g. July 1975.

5.13 PLASTICS

5.13.1 Process Description[1]

The manufacture of most resins or plastics begins with the polymerization or linking of the basic compound (monomer), usually a gas or liquid, into high molecular weight noncrystalline solids. The manufacture of the basic monomer is not considered part of the plastics industry and is usually accomplished at a chemical or petroleum plant.

The manufacture of most plastics involves an enclosed reaction or polymerization step, a drying step, and a final treating and forming step. These plastics are polymerized or otherwise combined in completely enclosed stainless steel or glass-lined vessels. Treatment of the resin after polmerization varies with the proposed use. Resins for moldings are dried and crushed or ground into molding powder. Resins such as the alkyd resins that are to be used for protective coatings are normally transferred to an agitated thinning tank, where they are thinned with some type of solvent and then stored in large steel tanks equipped with water-cooled condensers to prevent loss of solvent to the atmosphere. Still other resins are stored in latex form as they come from the kettle.

5.13.2 Emissions and Controls[1]

The major sources of air contamination in plastics manufacturing are the emissions of raw materials or monomers, emissions of solvents or other volatile liquids during the reaction, emissions of sublimed solids such as phthalic anhydride in alkyd production, and emissions of solvents during storage and handling of thinned resins. Emission factors for the manufacture of plastics are shown in Table 5.13-1.

Table 5.13-1. EMISSION FACTORS FOR PLASTICS MANUFACTURING WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: E

Type of plastic	Particulate		Gases	
	lb/ton	kg/MT	lb/ton	kg/MT
Polyvinyl chloride	35[b]	17.5[b]	17[c]	8.5[c]
Polypropylene	3	1.5	0.7[d]	0.35[d]
General	5 to 10	2.5 to 5	–	–

[a] References 2 and 3.

[b] Usually controlled with a fabric filter efficiency of 98 to 99 percent.

[c] As vinyl chloride.

[d] As propylene.

Much of the control equipment used in this industry is a basic part of the system and serves to recover a reactant or product. These controls include floating roof tanks or vapor recovery systems on volatile material, storage units, vapor recovery systems (adsorption or condensers), purge lines that vent to a flare system, and recovery systems on vacuum exhaust lines.

References for Section 5.13

1. Air Pollutant Emission Factors. Final Report. Resources Research, Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.

2. Unpublished data from industrial questionnaire. U.S. DHEW, PHS, National Air Pollution Control Administration, Division of Air Quality and Emissions Data. Durham, N.C. 1969.

3. Private Communication between Resources Research, Incorporated, and Maryland State Department of Health, Baltimore, Md. November 1969.

5.14 PRINTING INK

5.14.1 Process Description[1]

There are four major classes of printing ink: letterpress and lithographic inks, commonly called oil or paste inks; and flexographic and rotogravure inks, which are referred to as solvent inks. These inks vary considerably in physical appearance, composition, method of application, and drying mechanism. Flexographic and rotogravure inks have many elements in common with the paste inks but differ in that they are of very low viscosity, and they almost always dry by evaporation of highly volatile solvents.[2]

There are three general processes in the manufacture of printing inks: (1) cooking the vehicle and adding dyes, (2) grinding of a pigment into the vehicle using a roller mill, and (3) replacing water in the wet pigment pulp by an ink vehicle (commonly known as the flushing process).[3] The ink "varnish" or vehicle is generally cooked in large kettles at 200° to 600°F (93° to 315°C) for an average of 8 to 12 hours in much the same way that regular varnish is made. Mixing of the pigment and vehicle is done in dough mixers or in large agitated tanks. Grinding is most often carried out in three-roller or five-roller horizontal or vertical mills.

5.14.2 Emissions and Controls[1,4]

Varnish or vehicle preparation by heating is by far the largest source of ink manufacturing emissions. Cooling the varnish components — resins, drying oils, petroleum oils, and solvents — produces odorous emissions. At about 350°F (175°C) the products begin to decompose, resulting in the emission of decomposition products from the cooking vessel. Emissions continue throughout the cooking process with the maximum rate of emissions occuring just after the maximum temperature has been reached. Emissions from the cooking phase can be reduced by more than 90 percent with the use of scrubbers or condensers followed by afterburners.[4,5]

Compounds emitted from the cooking of oleoresinous varnish (resin plus varnish) include water vapor, fatty acids, glycerine, acrolein, phenols, aldehydes, ketones, terpene oils, terpenes, and carbon dioxide. Emissions of thinning solvents used in flexographic and rotogravure inks may also occur.

The quantity, composition, and rate of emissions from ink manufacturing depend upon the cooking temperature and time, the ingredients, the method of introducing additives, the degree of stirring, and the extent of air or inert gas blowing. Particulate emissions resulting from the addition of pigments to the vehicle are affected by the type of pigment and its particle size. Emission factors for the manufacture of printing ink are presented in Table 5.14-1.

Table 5.14-1. EMISSION FACTORS FOR PRINTING INK MANUFACTURING[a]
EMISSION FACTOR RATING: E

Type of process	Gaseous organic[b]		Particulates	
	lb/ton of product	kg/MT of product	lb/ton of pigment	kg/MT of pigment
Vehicle cooking				
General	120	60	–	–
Oils	40	20	–	–
Oleoresinous	150	75	–	–
Alkyds	160	80	–	–
Pigment mixing	–	–	2	1

[a] Based on data from section on paint and varnish.

[b] Emitted as gas, but rapidly condense as the effluent is cooled.

References for Section 5.14

1. Air Pollutant Emission Factors. Final Report. Resources Research Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.

2. Shreve, R. N. Chemical Process Industries, 3rd Ed. New York, McGraw Hill Book Co. 1967. p. 454-455.

3. Larsen, L.M. Industrial Printing Inks. New York, Reinhold Publishing Company. 1962.

4. Chatfield, H.E. Varnish Cookers. In: Air Pollution Engineering Manual. Danielson, J.A. (ed.). U.S. DHEW, PHS, National Center for Air Pollution Control. Cincinnati, Ohio. Publication Number 999-AP-40. 1967. p. 688-695.

5. Private communication with Interchemical Corporation, Ink Division. Cincinnati, Ohio. November 10, 1969.

5.15 SOAP AND DETERGENTS

5.15.1 Soap Manufacture[1]

The manufacture of soap entails the catalytic hydrolysis of various fatty acids with sodium or potassium hydroxide to form a glycerol-soap mixture. This mixture is separated by distillation, then neutralized and blended to produce soap. The main atmospheric pollution problem in the manufacture of soap is odor, and, if a spray drier is used, a particulate emission problem may also occur. Vent lines, vacuum exhausts, product and raw material storage, and waste streams are all potential odor sources. Control of these odors may be achieved by scrubbing all exhaust fumes and, if necessary, incinerating the remaining compounds. Odors emanating from the spray drier may be controlled by scrubbing with an acid solution.

5.15.2 Detergent Manufacture[1]

The manufacture of detergents generally begins with the sulfuration by sulfuric acid of a fatty alcohol or linear alkylate. The sulfurated compound is then neutralized with caustic solution (NaOH), and various dyes, perfumes, and other compounds are added.[2,3] The resulting paste or slurry is then sprayed under pressure into a vertical drying tower where it is dried with a stream of hot air (400° to 500°F or 204° to 260°C). The dried detergent is then cooled and packaged. The main source of particulate emissions is the spray-drying tower. Odors may also be emitted from the spray-drying operation and from storage and mixing tanks. Particulate emissions from spray-drying operations are shown in Table 5.15-1.

Table 5.15-1. PARTICULATE EMISSION FACTORS FOR SPRAY-DRYING DETERGENTS[a]
EMISSION FACTOR RATING: B

Control device	Overall efficiency, %	Particulate emissions	
		lb/ton of product	kg/MT of product
Uncontrolled	–	90	45
Cyclone[b]	85	14	7
Cyclone followed by:			
Spray chamber	92	7	3.5
Packed scrubber	95	5	2.5
Venturi scrubber	97	3	1.5

[a] Based on analysis of data in References 2 through 6.

[b] Some type of primary collector, such as a cyclone, is considered an integral part of the spray-drying system.

References for Section 5.15

1. Air Pollutant Emission Factors. Final Report. Resources Research Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.

2. Phelps, A.H. Air Pollution Aspects of Soap and Detergent Manufacture. J. Air Pol. Control Assoc. *17*(8):505-507. August 1967.

3. Shreve, R.N. Chemical Process Industries. 3rd Ed. New York, McGraw-Hill Book Company. 1967. p. 544-563.

4. Larsen, G.P., G.I. Fischer, and W.J. Hamming. Evaluating Sources of Air Pollution. Ind. Eng. Chem. *45*:1070-1074, May 1953.

5. McCormick, P.Y., R.L. Lucas, and D.R. Wells. Gas-Solid Systems. In: Chemical Engineer's Handbook. Perry, J.H. (ed.). New York, McGraw-Hill Book Company. 1963. p. 59.

6. Private communication with Maryland State Department of Health, Baltimore, Md. November 1969.

5.16 SODIUM CARBONATE (Soda Ash)

5.16.1 Process Description[1]

Soda ash is manufactured by three processes: (1) the natural or Lake Brine process, (2) the Solvay process (ammonia-soda), and (3) the electrolytic soda-ash process. Because the Solvay process accounts for over 80 percent of the total production of soda ash, it will be the only one discussed in this section.

In the Solvay process, the basic raw materials are ammonia, coke, limestone (calcium carbonate), and salt (sodium chloride). The salt, usually in the unpurified form of a brine, is first purified in a series of absorbers by precipitation of the heavy metal ions with ammonia and carbon dioxide. In this process sodium bicarbonate is formed. This bicarbonate coke is heated in a rotary kiln, and the resultant soda ash is cooled and conveyed to storage.

5.16.2 Emissions

The major source of emissions from the manufacture of soda ash is the release of ammonia. Small amounts of ammonia are emitted in the gases vented from the brine purification system. Intermittent losses of ammonia can also occur during the unloading of tank trucks into storage tanks. The major sources of dust emissions include rotary dryers, dry solids handling, and processing of lime. Dust emissions of fine soda ash also occur from conveyor transfer points and air classification systems, as well as during tank-car loading and packaging. Emission factors are summarized in Table 5.16-1.

Table 5.16-1. EMISSION FACTORS FOR SODA-ASH PLANTS WITHOUT CONTROLS
EMISSION FACTOR RATING: D

Type of source	Particulates		Ammonia	
	lb/ton	kg/MT	lb/ton	kg/MT
Ammonia recovery[a,b]	–	–	7	3.5
Conveying, transferring, loading, etc.[c]	6	3	–	–

[a] Reference 2.

[b] Represents ammonia loss following the recovery system.

[c] Based on data in References 3 through 5.

References for Section 5.16

1. Air Pollutant Emission Factors. Final Report. Resources Research, Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.

2. Shreve, R.N. Chemical Process Industries, 3rd Ed. New York, McGraw-Hill Book Company. 1967. p. 225-230.

3. Facts and Figures for the Chemical Process Industries. Chem. Eng. News. *43*:51-118, September 6, 1965.

4. Faith, W.L., D.B. Keyes, and R.L. Clark. Industrial Chemicals, 3rd Ed. New York, John Wiley and Sons, Inc. 1965.

5. Kaylor, F.B. Air Pollution Abatement Program of a Chemical Processing Industry. J. Air Pol. Control Assoc. *15*:65-67, February 1965.

5.17 SULFURIC ACID

Revised by William Vatavuk
and Donald Carey

5.17.1 Process Description

All sulfuric acid is made by either the lead chamber or the contact process. Because the contact process accounts for more than 97 percent of the total sulfuric acid production in the United States, it is the only process discussed in this section. Contact plants are generally classified according to the raw materials charged to them: (1) elemental sulfur burning, (2) spent acid and hydrogen sulfide burning, and (3) sulfide ores and smelter gas burning plants. The relative contributions from each type of plant to the total acid production are 68, 18.5, and 13.5 percent, respectively.

All contact processes incorporate three basic operations, each of which corresponds to a distinct chemical reaction. First, the sulfur in the feedstock is burned to sulfur dioxide:

$$\underset{\text{Sulfur}}{S} + \underset{\text{Oxygen}}{O_2} \rightarrow \underset{\text{Sulfur dioxide}}{SO_2}. \tag{1}$$

Then, the sulfur dioxide is catalytically oxidized to sulfur trioxide:

$$\underset{\text{Sulfur dioxide}}{2SO_2} + \underset{\text{Oxygen}}{O_2} \rightarrow \underset{\text{Sulfur trioxide}}{2SO_3}. \tag{2}$$

Finally, the sulfur trioxide is absorbed in a strong, aqueous solution of sulfuric acid:

$$\underset{\text{Sulfur trioxide}}{SO_3} + \underset{\text{Water}}{H_2O} \rightarrow \underset{\text{Sulfuric acid}}{H_2SO_4}. \tag{3}$$

5.17.1.1 Elemental Sulfur-Burning Plants[1,2] - Elemental sulfur, such as Frasch-process sulfur from oil refineries, is melted, settled, or filtered to remove ash and is fed into a combustion chamber. The sulfur is burned in clean air that has been dried by scrubbing with 93 to 99 percent sulfuric acid. The gases from the combustion chamber are cooled and then enter the solid catalyst (vanadium pentoxide) converter. Usually, 95 to 98 percent of the sulfur dioxide from the combustion chamber is converted to sulfur trioxide, with an accompanying large evolution of heat. After being cooled, the converter exit gas enters an absorption tower where the sulfur trioxide is absorbed with 98 to 99 percent sulfuric acid. The sulfur trioxide combines with the water in the acid and forms more sulfuric acid.

If oleum, a solution of uncombined SO_3 in H_2SO_4, is produced, SO_3 from the converter is first passed to an oleum tower that is fed with 98 percent acid from the absorption system. The gases from the oleum tower are then pumped to the absorption column where the residual sulfur trioxide is removed.

A schematic diagram of a contact process sulfuric acid plant that burns elemental sulfur is shown in Figure 5.17-1.

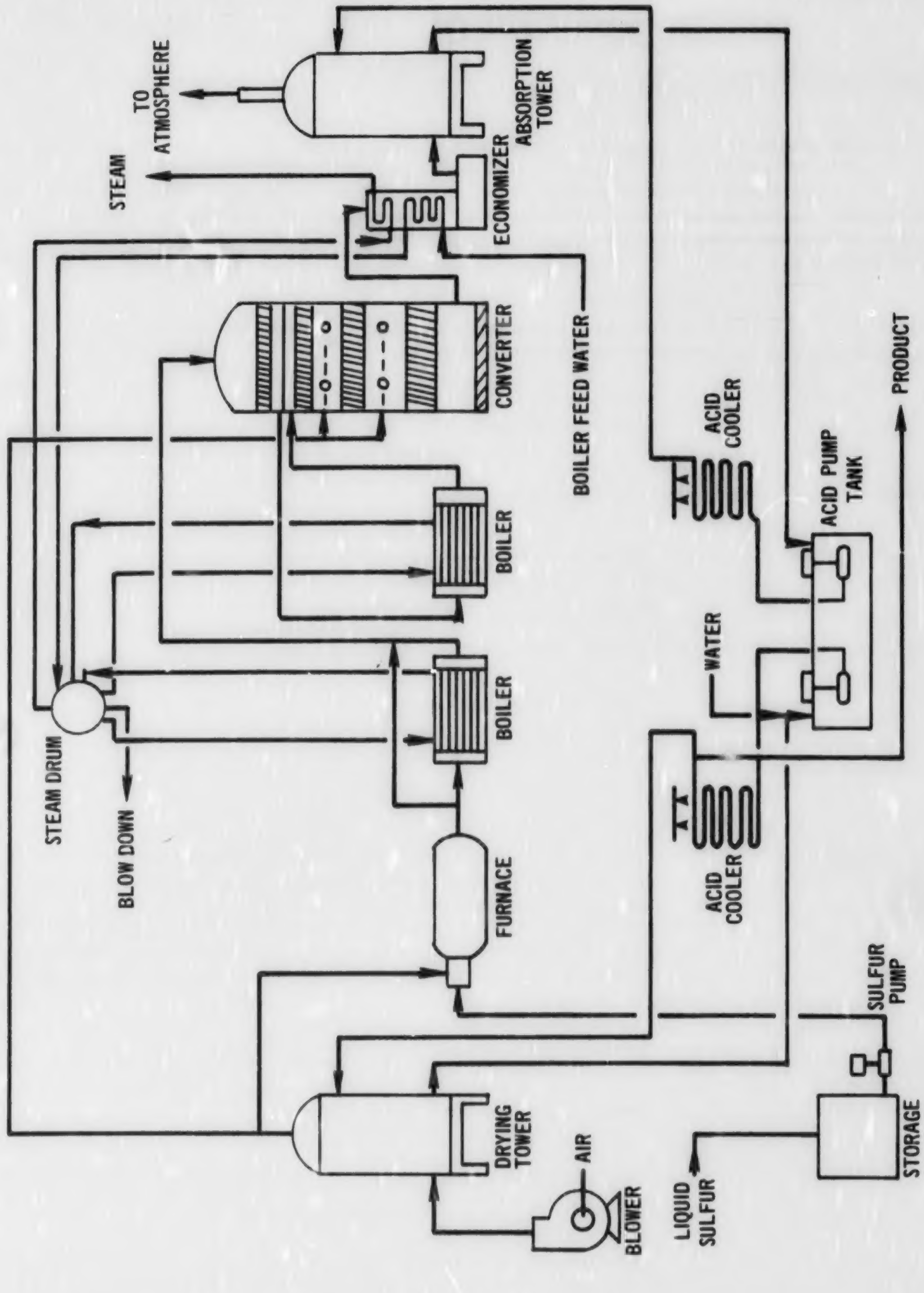

TO ATMOSPHERE
STEAM
ABSORPTION TOWER
ECONOMIZER
CONVERTER
BOILER FEED WATER
ACID COOLER
ACID PUMP TANK
PRODUCT
BOILER
BOILER
WATER
STEAM DRUM
BLOW DOWN
FURNACE
ACID COOLER
SULFUR PUMP
DRYING TOWER
AIR
BLOWER
STORAGE
LIQUID SULFUR

Figure 5.17-1. Basic flow diagram of contact-process sulfuric acid plant burning elemental sulfur.

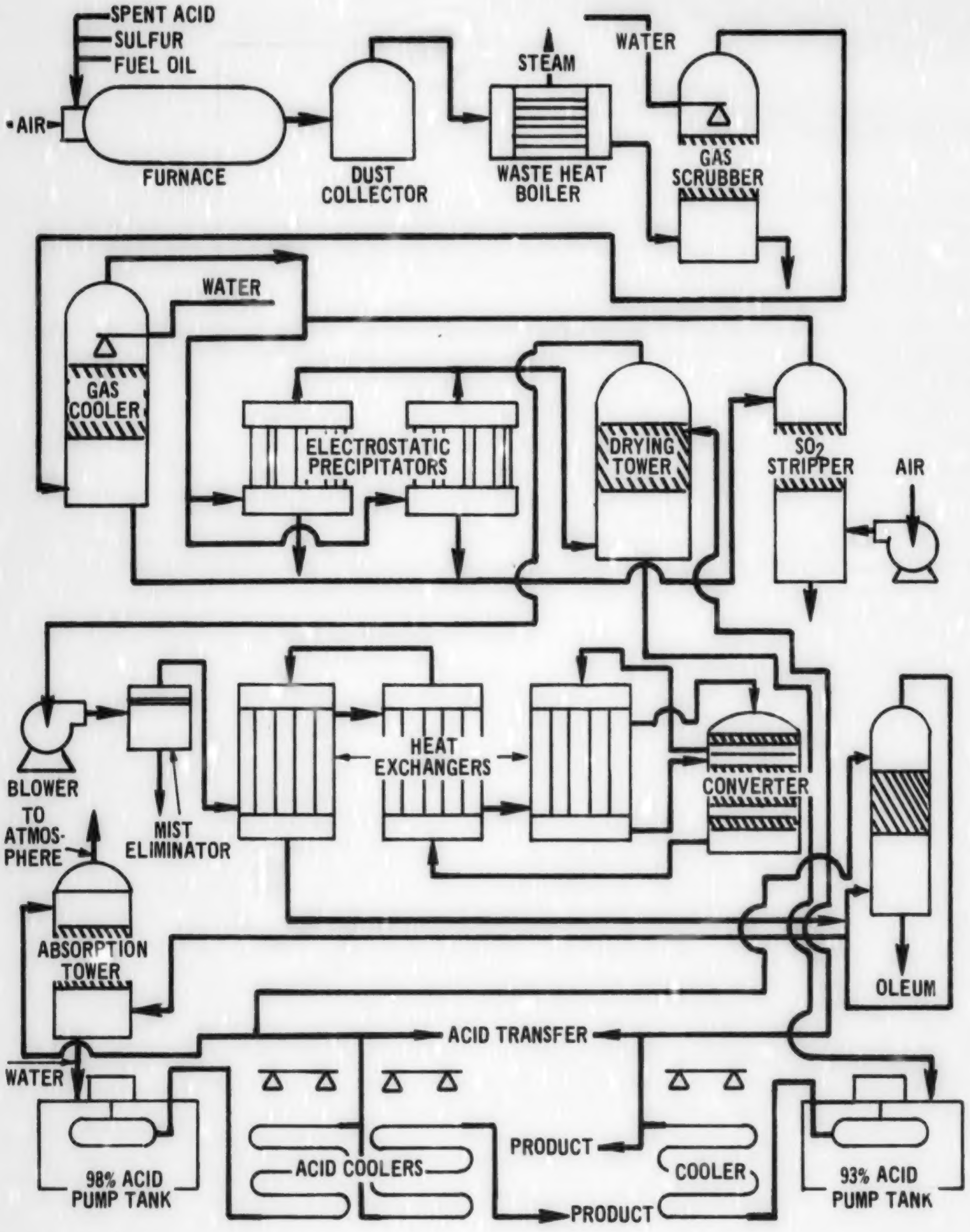

SPENT ACID
SULFUR
FUEL OIL
AIR
FURNACE
DUST COLLECTOR
STEAM
WASTE HEAT BOILER
WATER
GAS SCRUBBER
WATER
GAS COOLER
ELECTROSTATIC PRECIPITATORS
DRYING TOWER
SO2 STRIPPER
AIR
BLOWER
MIST ELIMINATOR
HEAT EXCHANGERS
CONVERTER
TO ATMOSPHERE
ABSORPTION TOWER
OLEUM
ACID TRANSFER
WATER
98% ACID PUMP TANK
ACID COOLERS
PRODUCT
PRODUCT
COOLER
93% ACID PUMP TANK

Figure 5.17-2. Basic flow diagram of contact-process sulfuric acid plant burning spent acid.

5.17.1.2 Spent Acid and Hydrogen Sulfide Burning Plants[1,2] - Two types of plants are used to process this type of sulfuric acid. In one the sulfur dioxide and other combustion products from the combustion of spent acid and/or hydrogen sulfide with undried atmospheric air are passed through gas-cleaning and mist-removal equipment. The gas stream next passes through a drying tower. A blower draws the gas from the drying tower and discharges the sulfur dioxide gas to the sulfur trioxide converter. A schematic diagram of a contact-process sulfuric acid plant that burns spent acid is shown in Figure 5.17-2.

In a "wet-gas plant," the wet gases from the combustion chamber are charged directly to the converter with no intermediate treatment. The gas from the converter flows to the absorber, through which 93 to 98 percent sulfuric acid is circulating.

5.17.1.3 Sulfide Ores and Smelter Gas Plants - The configuration of this type of plant is essentially the same as that of a spent-acid plant (Figure 5.17-2) with the primary exception that a roaster is used in place of the combustion furnace.

The feed used in these plants is smelter gas, available from such equipment as copper converters, reverberatory furnaces, roasters, and flash smelters. The sulfur dioxide in the gas is contaminated with dust, acid mist, and gaseous impurities. To remove the impurities the gases must be cooled to essentially atmospheric temperature and passed through purification equipment consisting of cyclone dust collectors, electrostatic dust and mist precipitators, and scrubbing and gas-cooling towers. After the gases are cleaned and the excess water vapor is removed, they are scrubbed with 98 percent acid in a drying tower. Beginning with the drying tower stage, these plants are nearly identical to the elemental sulfur plants shown in Figure 5.17-1.

5.17.2 Emissions and Controls

5.17.2.1 Sulfur Dioxide[1-3] - Nearly all sulfur dioxide emissions from sulfuric acid plants are found in the exit gases. Extensive testing has shown that the mass of these SO_2 emissions is an inverse function of the sulfur conversion efficiency (SO_2 oxidized to SO_3). This conversion is, in turn, affected by the number of stages in the catalytic converter, the amount of catalyst used, the temperature and pressure, and the concentrations of the reactants, sulfur dioxide and oxygen. For example, if the inlet SO_2 concentration to the converter were 8 percent by volume (a representative value), and the conversion temperature were 473°C, the conversion efficiency would be 96 percent. At this conversion, the uncontrolled emission factor for SO_2 would be 55 pounds per ton (27.5 kg/MT) of 100 percent sulfuric acid produced, as shown in Table 5.17-1. For purposes of comparison, note that the Environmental Protection Agency performance standard[3] for new and modified plants is 4 pounds per ton (2kg / MT) of 100 percent acid produced, maximum 2-hour average. As Table 5.17-1 and Figure 5.17-3 indicate, achieving this standard requires a conversion efficiency of 99.7 percent in an uncontrolled plant or the equivalent SO_2 collection mechanism in a controlled facility. Most single absorption plants have SO_2 conversion efficiencies ranging from 95 to 98 percent.

In addition to exit gases, small quantities of sulfur oxides are emitted from storage tank vents and tank car and tank truck vents during loading operations; from sulfuric acid concentrators; and through leaks in process equipment. Few data are available on emissions from these sources.

Of the many chemical and physical means for removing SO_2 from gas streams, only the dual absorption and the sodium sulfite-bisulfite scrubbing processes have been found to increase acid production without yielding unwanted by-products.

Table 5.17-1. EMISSION FACTORS FOR SULFURIC ACID PLANTS[a]
EMISSION FACTOR RATING: A

Conversion of SO_2 to SO_3, %	SO_2 emissions	
	lb/ton of 100 % H_2SO_4	kg/MT of 100 % H_2SO_4
93	96	48.0
94	82	41.0
95	70	35.0
96	55	27.5
97	40	20.5
98	27	13.0
99	14	7.0
99.5	7	3.5
99.7	4	2.0
100	0	0.0

[a] Reference 1.

[b] The following linear interpolation formula can be used for calculating emission factors for conversion efficiencies between 93 and 100 percent: emission factor (lb/ton acid) = -13.65 (percent conversion efficiency) + 1365.

In the dual absorption process, the SO_3 gas formed in the primary converter stages is sent to a primary absorption tower where H_2SO_4 is formed. The remaining unconverted sulfur dioxide is forwarded to the final stages in the converter, from whence it is sent to the secondary absorber for final sulfur trioxide removal. The result is the conversion of a much higher fraction of SO_2 to SO_3 (a conversion of 99.7 percent or higher, on the average, which meets the performance standard). Furthermore, dual absorption permits higher converter inlet sulfur dioxide concentrations than are used in single absorption plants because the secondary conversion stages effectively remove any residual sulfur dioxide from the primary absorber.

Where dual absorption reduces sulfur dioxide emissions by increasing the overall conversion efficiency, the sodium sulfite-bisulfite scrubbing process removes sulfur dioxide directly from the absorber exit gases. In one version of this process, the sulfur dioxide in the waste gas is absorbed in a sodium sulfite solution, separated, and recycled to the plant. Test results from a 750 ton (680 MT) per day plant equipped with a sulfite scrubbing system indicated an average emission factor of 2.7 pounds per ton (1.35 kg/MT).

15.17.2.2 Acid Mist[1-3] - Nearly all the acid mist emitted from sulfuric acid manufacturing can be traced to the absorber exit gases. Acid mist is created when sulfur trioxide combines with water vapor at a temperature below the dew point of sulfur trioxide. Once formed within the process system, this mist is so stable that only a small quantity can be removed in the absorber.

In general, the quantity and particle size distribution of acid mist are dependent on the type of sulfur feedstock used, the strength of acid produced, and the conditions in the absorber. Because it contains virtually no water vapor, bright elemental sulfur produces little acid mist when burned; however, the hydrocarbon impurities in other feedstocks – dark sulfur, spent acid, and hydrogen sulfide – oxidize to water vapor during combustion. The water vapor, in turn, combines with sulfur trioxide as the gas cools in the system.

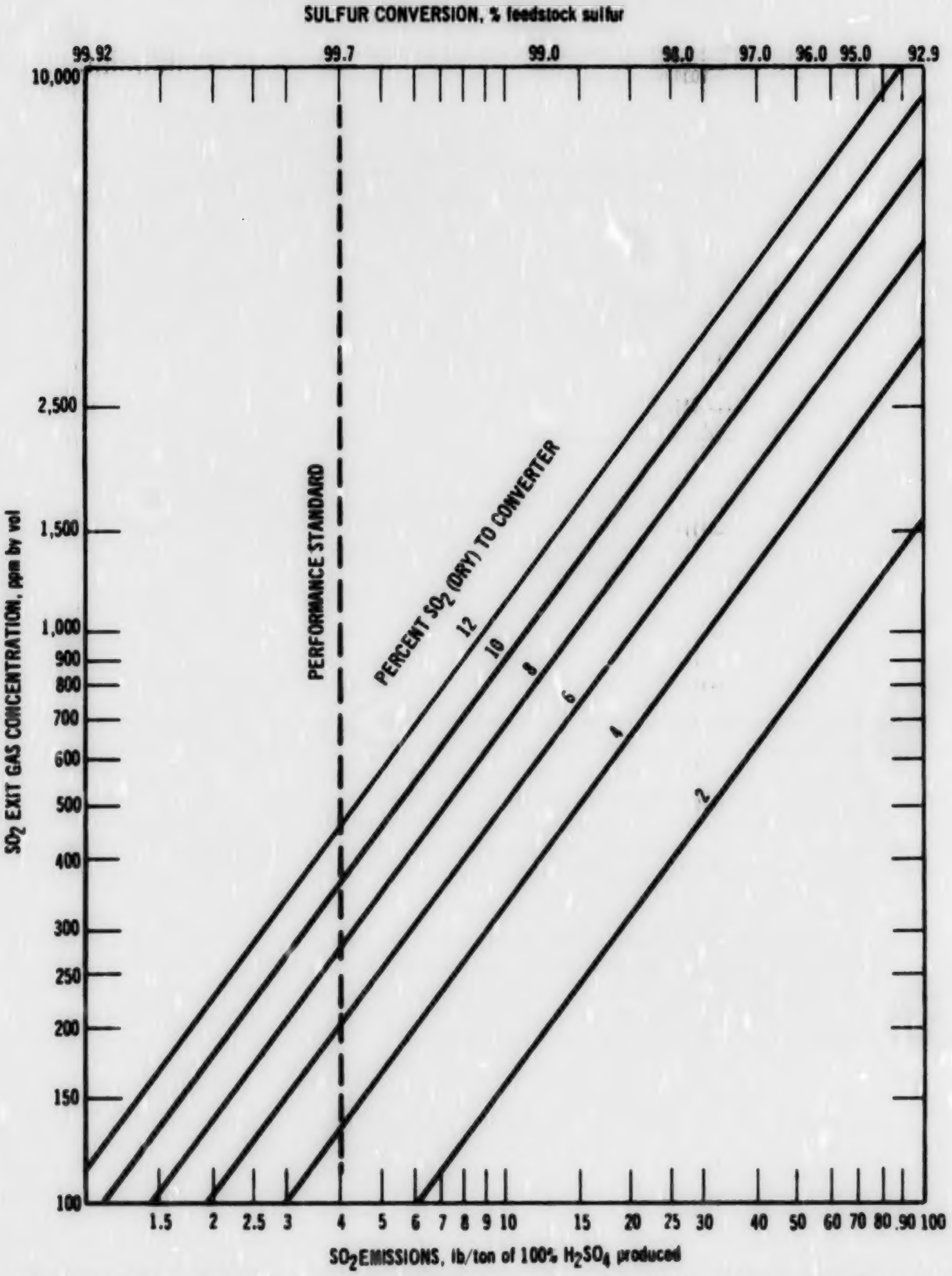


Figure 5.17-3. Sulfuric acid plant feedstock sulfur conversion versus volumetric and mass SO_2 emissions at various inlet SO_2 concentrations by volume.

The strength of acid produced–whether oleum or 99 percent sulfuric acid–also affects mist emissions. Oleum plants produce greater quantities of finer, more stable mist. For example, uncontrolled mist emissions from oleum plants burning spent acid range from 0.1 to 10.0 pounds per ton (0.05 to 5.0 kg/MT), while those from 98 percent acid plants burning elemental sulfur range from 0.4 to 4.0 pounds per ton (0.2 to 2.0 kg/MT). Furthermore, 85 to 95 weight percent of the mist particles from oleum plants are less than 2 microns in diameter, compared with only 30 weight percent that are less than 2 microns in diameter from 98 percent acid plants.

The operating temperature of the absorption column directly affects sulfur trioxide absorption and, accordingly, the quality of acid mist formed after exit gases leave the stack. The optimum absorber operating temperature is dependent on the strength of the acid produced, throughput rates, inlet sulfur trioxide concentrations, and other variables peculiar to each individual plant. Finally, it should be emphasized that the percentage conversion of sulfur dioxide to sulfur trioxide has no direct effect on acid mist emissions. In Table 5.17-2 uncontrolled acid mist emissions are presented for various sulfuric acid plants.

Two basic types of devices, electrostatic precipitators and fiber mist eliminators, effectively reduce the acid mist concentration from contact plants to less than the EPA new-source performance standard, which is 0.15 pound per ton (0.075 kg/MT) of acid. Precipitators, if properly maintained, are effective in collecting the mist particles at efficiencies up to 99 percent (see Table 5.17-3).

The three most commonly used fiber mist eliminators are the vertical tube, vertical panel, and horizontal dual-pad types. They differ from one another in the arrangement of the fiber elements, which are composed of either chemically resistant glass or fluorocarbon, and in the means employed to collect the trapped liquid. The operating characteristics of these three types are compared with electrostatic precipitators in Table 5.17-3.

Table 5.17-2. ACID MIST EMISSION FACTORS FOR SULFURIC ACID PLANTS WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: B

Raw material	Oleum produced, % total output	Emissions[b] lb/ton acid	kg/MT acid
Recovered sulfur	0 to 43	0.35 to 0.8	0.175 to 0.4
Bright virgin sulfur	0	1.7	0.85
Dark virgin sulfur	33 to 100	0.32 to 6.3	0.16 to 3.15
Sulfide ores	0 to 25	1.2 to 7.4	0.6 to 3.7
Spent acid	0 to 77	2.2 to 2.7	1.1 to 1.35

[a] Reference 1.

[b] Emissions are proportional to the percentage of oleum in the total product. Use the low end of ranges for low oleum percentage and high end of ranges for high oleum percentage.

Table 5.17-3. EMISSION COMPARISON AND COLLECTION EFFICIENCY OF TYPICAL ELECTROSTATIC PRECIPITATOR AND FIBER MIST ELIMINATORS[a]

Control device	Particle size collection efficiency, %		Acid mist emissions			
			98% acid plants[b]		oleum plants	
	>3 μm	≤3 μm	lb/ton	kg/MT	lb/ton	kg/MT
Electrostatic precipitator	99	100	0.10	0.05	0.12	0.06
Fiber mist eliminator						
Tubular	100	95 to 99	0.02	0.01	0.02	0.01
Panel	100	90 to 98	0.10	0.05	0.10	0.05
Dual pad	100	93 to 99	0.11	0.055	0.11	0.055

[a] Reference 2.

[b] Based on manufacturers' generally expected results; calculated for 8 percent sulfur dioxide concentration in gas converter.

References for Section 5.17

1. Atmospheric Emissions from Sulfuric Acid Manufacturing Processes. U.S. DHEW, PHS, National Air Pollution Control Administration. Washington, D.C. Publication Number 999-AP-13. 1966.

2. Unpublished report on control of air pollution from sulfuric acid plants. Environmental Protection Agency. Research Triangle Park, N.C. August 1971.

3. Standards of Performance for New Stationary Sources. Environmental Protection Agency. Washington, D.C. Federal Register. *36*(247): December 23, 1971.

5.18 SULFUR

By William Vatavuk

5.18.1 Process Description

Nearly all of the elemental sulfur produced from hydrogen sulfide is made by the modified Claus process. The process (Figure 5.18-1) consists of the multi-stage oxidation of hydrogen sulfide according to the following reaction:

$$\begin{array}{ccccccc} 2H_2S & + & O_2 & \longrightarrow & 2S & + & 2H_2O \\ \text{Hydrogen} & & \text{Oxygen} & & \text{Sulfur} & & \text{Water} \\ \text{sulfide} & & & & & & \end{array}$$

In the first step, approximately one-third of the hydrogen sulfide is reacted with air in a pressurized boiler (1.0 to 1.5 atmosphere) where most of the heat of reaction and some of the sulfur are removed. After removal of the water vapor and sulfur, the cooled gases are heated to between 400 and 500°F, and passed over a "Claus" catalyst bed composed of bauxite or alumina, where the reaction is completed. The degree of reaction conpletion is a function of the number of catalytic stages employed. Two stages can recover 92 to 95 percent of the potential sulfur; three stages, 95 to 96 percent; and four stages, 96 to 97 percent. The conversion to sulfur is ultimately limited by the reverse reaction in which water vapor recombines with sulfur to form gaseous hydrogen sulfide and sulfur dioxide. Additional amounts of sulfur are lost as vapor, entrained mist, or droplets and as carbonyl sulfide and carbon disulfide (0.25 to 2.5 percent of the sulfur fed). The latter two compounds are formed in the pressurized boiler at high temperature (1500 to 2500°F) in the presence of carbon compounds.

The plant tail gas, containing the above impurities in volume quantities of 1 to 3 percent, usually passes to an incinerator, where all of the sulfur is oxidized to sulfur dioxide at temperatures ranging from 1000 to 1200°F. The tail gas containing the sulfur dioxide then passes to the atmosphere via a stack.

5.18.2 Emissions and Controls[1,2]

Virtually all of the emissions from sulfur plants consist of sulfur dioxide, the main incineration product. The quantity of sulfur dioxide emitted is, in turn, a function of the number of conversion stages employed. the process temperature and pressure, and the amounts of carbon compounds present in the pressurized boiler.

The most commonly used control method involves two main steps – conversion of sulfur dioxide to hydrogen sulfide followed by the conversion of hydrogen sulfide to elemental sulfur. Conversion of sulfur dioxide to hydrogen sulfide occurs via catalytic hydrogenation or hydrolysis at temperatures from 600 to 700°F. The products are cooled to remove the water vapor and then reacted with a sodium carbonate solution to yield sodium hydrosulfide. The hydrosulfide is oxidized to sulfur in solution by sodium vanadate. Finely divided sulfur appears as a froth that is skimmed off, washed, dried by centrifugation, and added to the plant product. Overall recovery of sulfur approaches 100 percent if this process is employed. Table 5.18-1 lists emissions from controlled and uncontrolled sulfur plants.

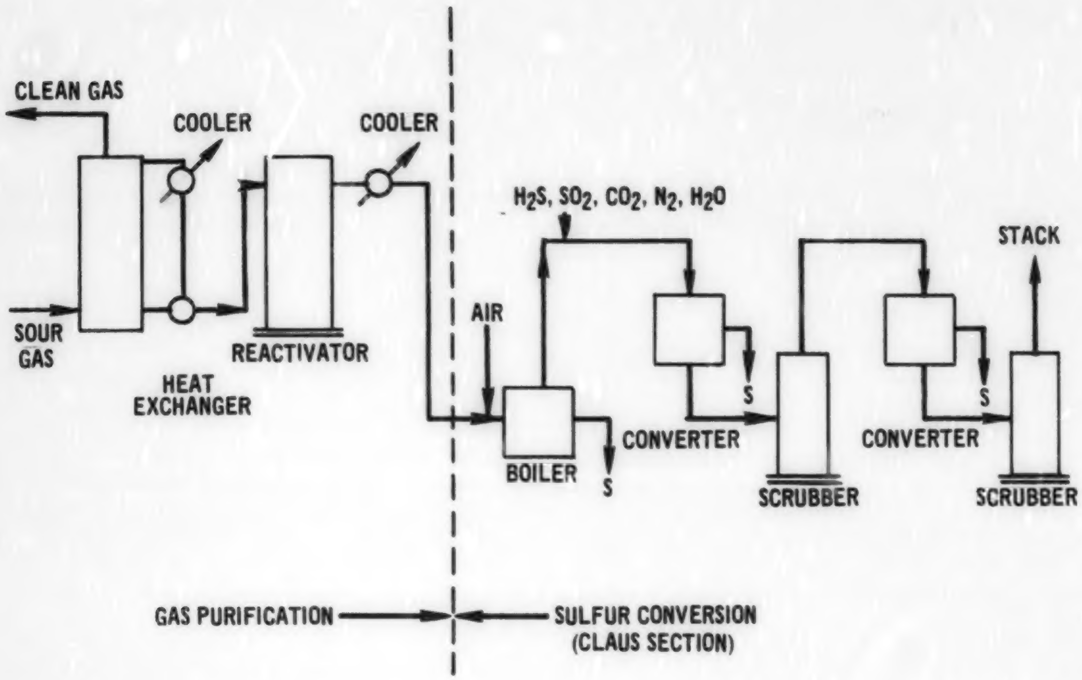

CLEAN GAS
COOLER
COOLER
H2S, SO2, CO2, N2, H2O
STACK
AIR
SOUR GAS
REACTIVATOR
HEAT EXCHANGER
S
S
CONVERTER
CONVERTER
BOILER
S
SCRUBBER
SCRUBBER
GAS PURIFICATION
SULFUR CONVERSION (CLAUS SECTION)

Figure 5.18-1. Basic flow diagram of modified Claus process with two converter stages used in manufacturing sulfur.

Table 5.18-1. EMISSION FACTORS FOR MODIFIED-CLAUS SULFUR PLANTS EMISSION FACTOR RATING: D

Number of catalytic stages	Recovery of of sulfur, %	SO_2 emissions[a] lb/ton 100% sulfur	SO_2 emissions[a] kg/MT 100% sulfur
Two, uncontrolled	92 to 95	211 to 348	106 to 162
Three, uncontrolled	95 to 96	167 to 211	84 to 106
Four, uncontrolled	96 to 97	124 to 167	62 to 84
Sulfur removal process	99.9	4.0	2.0

[a] The range in emission factors corresponds to the range in the percentage recovery of sulfur.

References for Section 5.18

1. Beavon, David K. Abating Sulfur Plant Tail Gases. Pollution Engineering. *4*(1):34-35, January 1972.

2. Kirk-Othmer Encyclopedia of Chemical Technology, Vol. 19. New York, John Wiley and Sons, Inc. 1969.

5.19 SYNTHETIC FIBERS

5.19.1 Process Description[1]

Synthetic fibers are classified into two major categories, semi-synthetic and "true" synthetic. Semi-synthetics, such as viscose rayon and acetate fibers, result when natural polymeric materials such as cellulose are brought into a dissolved or dispersed state and then spun into fine filaments. True synthetic polymers, such as Nylon, * Orlon, and Dacron, result from addition and other polymerization reactions that form long chain molecules.

True synthetic fibers begin with the preparation of extremely long, chain-like molecules. The polymer is spun in one of four ways:[2] (1) melt spinning, in which molten polymer is pumped through spinneret jets, the polymer solidifying as it strikes the cool air; (2) dry spinning, in which the polymer is dissolved in a suitable organic solvent, and the resulting solution is forced through spinnerets; (3) wet spinning, in which the solution is coagulated in a chemical as it emerges from the spinneret; and (4) core spinning, the newest method, in which a continuous filament yarn together with short-length "hard" fibers is introduced onto a spinning frame in such a way as to form a composite yarn.

5.19.2 Emissions and Controls[1]

In the manufacture of viscose rayon, carbon disulfide and hydrogen sulfide are the major gaseous emissions. Air pollution controls are not normally used to reduce these emissions, but adsorption in activated carbon at an efficiency of 80 to 95 percent, with subsequent recovery of the CS_2 can be accomplished.[3] Emissions of gaseous hydrocarbons may also occur from the drying of the finished fiber. Table 5.19-1 presents emission factors for semi-synthetic and true synthetic fibers.

Table 5.19-1. EMISSION FACTORS FOR SYNTHETIC FIBERS MANUFACTURING
EMISSION FACTOR RATING: E

Type of fiber	Hydrocarbons		Carbon disulfide		Hydrogen sulfide		Oil vapor or mist	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Semi-synthetic								
Viscose rayon[a,b]	–	–	55	27.5	6	3	–	–
True synthetic[c]								
Nylon	7	3.5	–	–	–	–	15	7.5
Dacron	–	–	–	–	–	–	7	3.5

[a] Reference 4.
[b] May be reduced by 80 to 95 percent adsorption in activated charcoal.[3]
[c] Reference 5.

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*Mention of company or product names does not constitute endorsement by the Environmental Protection Agency.

References for Section 5.19

1. Air Pollutant Emission Factors. Final Report. Resources Research, Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.

2. Fibers, Man-Made. In: Kirk-Othmer Encyclopedia of Chemical Technology. New York, John Wiley and Sons, Inc. 1969.

3. Fluidized Recovery System Nabs Carbon Disulfide. Chem. Eng. *70*(8):92-94, April 15, 1963.

4. Private communication between Resources Research, Incorporated, and Rayon Manufacturing Plant. December 1969.

5. Private communication between Resources Research, Incorporated, and E.I. Dupont de Nemours and Company. January 13, 1970.

5.20 SYNTHETIC RUBBER

5.20.1 Process Description[1]

Copolymers of butadiene and styrene, commonly known as SBR, account for more than 70 percent of all synthetic rubber produced in the United States. In a typical SBR manufacturing process, the monomers of butadiene and styrene are mixed with additives such as soaps and mercaptans. The mixture is polymerized to a conversion point of approximately 60 percent. After being mixed with various ingredients such as oil and carbon black, the latex product is coagulated and precipitated from the latex emulsion. The rubber particles are then dried and baled.

5.20.2 Emissions and Controls[1]

Emissions from the synthetic rubber manufacturing process consist of organic compounds (largely the monomers used) emitted from the reactor and blow-down tanks, and particulate matter and odors from the drying operations.

Drying operations are frequently controlled with fabric filter systems to recover any particulate emissions, which represent a product loss. Potential gaseous emissions are largely controlled by recycling the gas stream back to the process. Emission factors from synthetic rubber plants are summarized in Table 5.20-1.

Table 5.20-1. EMISSION FACTORS FOR SYNTHETIC RUBBER PLANTS: BUTADIENE-ACRYLONITRILE AND BUTADIENE-STYRENE
EMISSION FACTOR RATING: E

Compound	Emissions[a,b]	
	lb/ton	kg/MT
Alkenes		
Butadiene	40	20
Methyl propene	15	7.5
Butyne	3	1.5
Pentadiene	1	0.5
Alkanes		
Dimethylheptane	1	0.5
Pentane	2	1
Ethanenitrile	1	0.5
Carbonyls		
Acrylonitrile	17	8.5
Acrolein	3	1.5

[a] The butadiene emission is not continuous and is greatest right after a batch of partially polymerized latex enters the blow-down tank.

[b] References 2 and 3.

References for Section 5.20

1. Air Pollutant Emission Factors. Final Report. Resources Research Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham. N.C., under Contract Number CPA-22-69-119. April 1970.

2. The Louisville Air Pollution Study. U.S. DHEW, PHS, Division of Air Pollution. Cincinnati, Ohio. 1961. p. 26-27 and 124.

3. Unpublished data from synthetic rubber plant. U.S. DHEW, PHS. EHS, National Air Pollution Control Administration, Division of Air Quality and Emissions Data. Durham, N.C. 1969.

5.21 TERESPHTHALIC ACID

5.21.1 Process Description[1,2]

The main use of terephthalic acid is to produce dimethylterephthalate, which is used for polyester fibers (like Dacron) and films. Terephthalic acid can be produced in various ways, one of which is the oxidation of *p*-xylene by nitric acid. In this process an oxygen-containing gas (usually air), *p*-xylene, and HNO_3 are all passed into a reactor where oxidation by the nitric acid takes place in two steps. The first step yields primarily N_2O; the second step yields mostly NO in the offgas. The terephthalic acid precipitated from the reactor effluent is recovered by conventional crystallization, separation, and drying operations.

5.21.2 Emissions

The NO in the offgas from the reactor is the major air contaminant from the manufacture of terephthalic acid. The amount of nitrogen oxides emitted is roughly estimated in Table 5.21-1.

Table 5.21-1. NITROGEN OXIDES EMISSION FACTORS FOR TEREPHTHALIC ACID PLANTS[a]
EMISSION FACTOR RATING: D

Type of operation	Nitrogen oxides (NO)	
	lb/ton	kg/MT
Reactor	13	6.5

[a] Reference 2.

References for Section 5.21

1. Air Pollutant Emission Factors. Final Report. Resources Research, Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C. under Contract Number CPA-22-69-119. April 1970.

2. Terephthalic Acid. In: Kirk-Othmer Encyclopedia of Chemical Technology, Vol. 9. New York, John Wiley and Sons, Inc. 1964.

6. FOOD AND AGRICULTURAL INDUSTRY

Before food and agricultural products are used by the consumer they undergo a number of processing steps, such as refinement, preservation, and product improvement, as well as storage and handling, packaging, and shipping. This section deals with the processing of food and agricultural products and the intermediate steps that present air pollution problems. Emission factors are presented for industries where data were available. The primary pollutant emitted from these processes is particulate matter.

6.1 ALFALFA DEHYDRATING

by Tom Lahre

6.1.1 General[1-3]

Dehydrated alfalfa is a meal product resulting from the rapid drying of alfalfa by artifical means at temperatures above 212°F (100°C). Alfalfa meal is used in chicken rations, cattle feed, hog rations, sheep feed, turkey mash, and other formula feeds. It is important for its protein content, growth and reproductive factors, pigmenting xanthophylls, and vitamin contributions.

A schematic of a generalized alfalfa dehydrator plant is given in Figure 6.1-1. Standing alfalfa is mowed and chopped in the field and transported by truck to a dehydrating plant, which is usually located within 10 miles of the field. The truck dumps the chopped alfalfa (wet chops) onto a self-feeder, which carries it into a direct-fired, rotary drum. Within the drum, the wet chops are dried from an initial moisture content of about 60 to 80 percent (by weight) to about 8 to 16 percent. Typical combustion gas temperatures within the oil- or gas-fired drums range from 1800 to 2000°F (980 to 1092°C) at the inlet to 250 to 300°F (120 to 150°C) at the outlet.

From the drying drum, the dry chops are pneumatically conveyed into a primary cyclone that separates them from the high-moisture, high-temperature exhaust stream. From the primary cyclone, the chops are fed into a hammermill, which grinds the dry chops into a meal. The meal is pneumatically conveyed from the hammermill into a meal collector cyclone in which the meal is separated from the airstream and discharged into a holding bin. Meal is then fed into a pellet mill where it is steam conditioned and extruded into pellets.

From the pellet mill, the pellets are either pneumatically or mechanically conveyed to a cooler, through which air is drawn to cool the pellets and, in some cases, remove fines. Fines removal is more commonly effected in shaker screens following or ahead of the cooler, with the fines being conveyed back into the meal collector cyclone, meal bin, or pellet mill. Cyclone separators may be employed to separate entrained fines in the cooler exhaust and to collect pellets when the pellets are pneumatically conveyed from the pellet mill to the cooler.

Following cooling and screening, the pellets are transferred to bulk storage. Dehydrated alfalfa is most often stored and shipped in pellet form; however, in some instances, the pellets may be ground in a hammermill and shipped in meal form. When the finished pellets or ground pellets are pneumatically transferred to storage or loadout, additional cyclones may be employed for product airstream separation at these locations.

6.1.2 Emissions and Controls[1-3]

Particulate matter is the primary pollutant of concern from alfalfa dehydrating plants although some odors arise from the organic volatiles driven off during drying. Although the major source is the primary cooling cyclone, lesser sources include the downstream cyclone separators and the bagging and loading operations.

Emission factors for the various cyclone separators utilized in alfalfa dehydrating plants are given in Table 6.1-1. Note that, although these sources are common to many plants, there will be considerable variation from the generalized flow diagram in Figure 6.1-1 depending on the desired nature of the product, the physical layout of the plant, and the modifications made for air pollution control. Common variations include ducting the exhaust gas stream from one or more of the downstream cyclones back through the primary cyclone and ducting a portion of the primary cyclone exhaust back into the furnace. Another modification involves ducting a part of the meal collector cyclone exhaust back into the hammermill, with the remainder ducted to the primary cyclone or discharged directly to the atmosphere. Also, additional cyclones may be employed if the pellets are pneumatically rather than mechanically conveyed from the pellet mill to the cooler or if the finished pellets or ground pellets are pneumatically conveyed to storage or loadout.

Table 6.1-1. PARTICULATE EMISSION FACTORS FOR ALFALFA DEHYDRATING PLANTS
EMISSION FACTOR RATING: PRIMARY CYCLONES: A
ALL OTHER SOURCES: C

Sources[a]	Emissions	
	lb/ton of product[b]	kg/MT of product[b]
Primary cyclone	10[c]	5[c]
Meal collector cyclone[d]	2.6	1.3
Pellet collector cyclone[e]	Not available	Not available
Pellet cooler cyclone[f]	3	1.5
Pellet regrind cyclone[g]	8	4
Storage bin cyclone[h]	Neg.	Neg.

[a] The cyclones used for product/airstream separation are the air pollution sources in alfalfa dehydrating plants. All factors are based on References 1 and 2.

[b] Product consists of meal or pellets. These factors can be applied to the quantity of incoming wet chops by dividing by a factor of four.

[c] This average factor may be used even when other cyclone exhaust streams are ducted back into the primary cyclone. Emissions from primary cyclones may range from 3 to 35 lb/ton (1.5 to 17.5 kg/MT) of product and are more a function of the operating procedures and process modifications made for air pollution control than whether other cyclone exhausts are ducted back through the primary cyclone. Use 3 to 15 lb/ton (1.5 to 7.5 kg/MT) for plants employing good operating procedures and process modifications for air pollution control. Use higher values for older, unmodified, or less well run plants.

[d] This cyclone is also called the air meal separator or hammermill cyclone. When the meal collector exhaust is ducted back to the primary cyclone and/or the hammermill, this cyclone is no longer a source.

[e] This cyclone will only be present if the pellets are pneumatically transferred from the pellet mill to the pellet cooler.

[f] This cyclone is also called the pellet meal air separator or pellet mill cyclone. When the pellet cooler cyclone exhaust is ducted back into the primary cyclone, it is no longer a source.

[g] This cyclone is also called the pellet regrind air separator. Regrind operations are more commonly found at terminal storage facilities than at dehydrating plants.

[h] Small cyclone collectors may be used to collect the finished pellets when they are pneumatically transferred to storage.

Air pollution control (and product recovery) is accomplished in alfalfa dehydrating plants in a variety of ways. A simple, yet effective technique is the proper maintenance and operation of the alfalfa dehydrating equipment. Particulate emissions can be reduced significantly if the feeder discharge rates are uniform, if the dryer furnace is operated properly, if proper airflows are employed in the cyclone collectors, and if the hammermill is well maintained and not overloaded. It is especially important in this regard not to overdry and possibly burn the chops as this results in the generation of smoke and increased fines in the grinding and pelletizing operations.

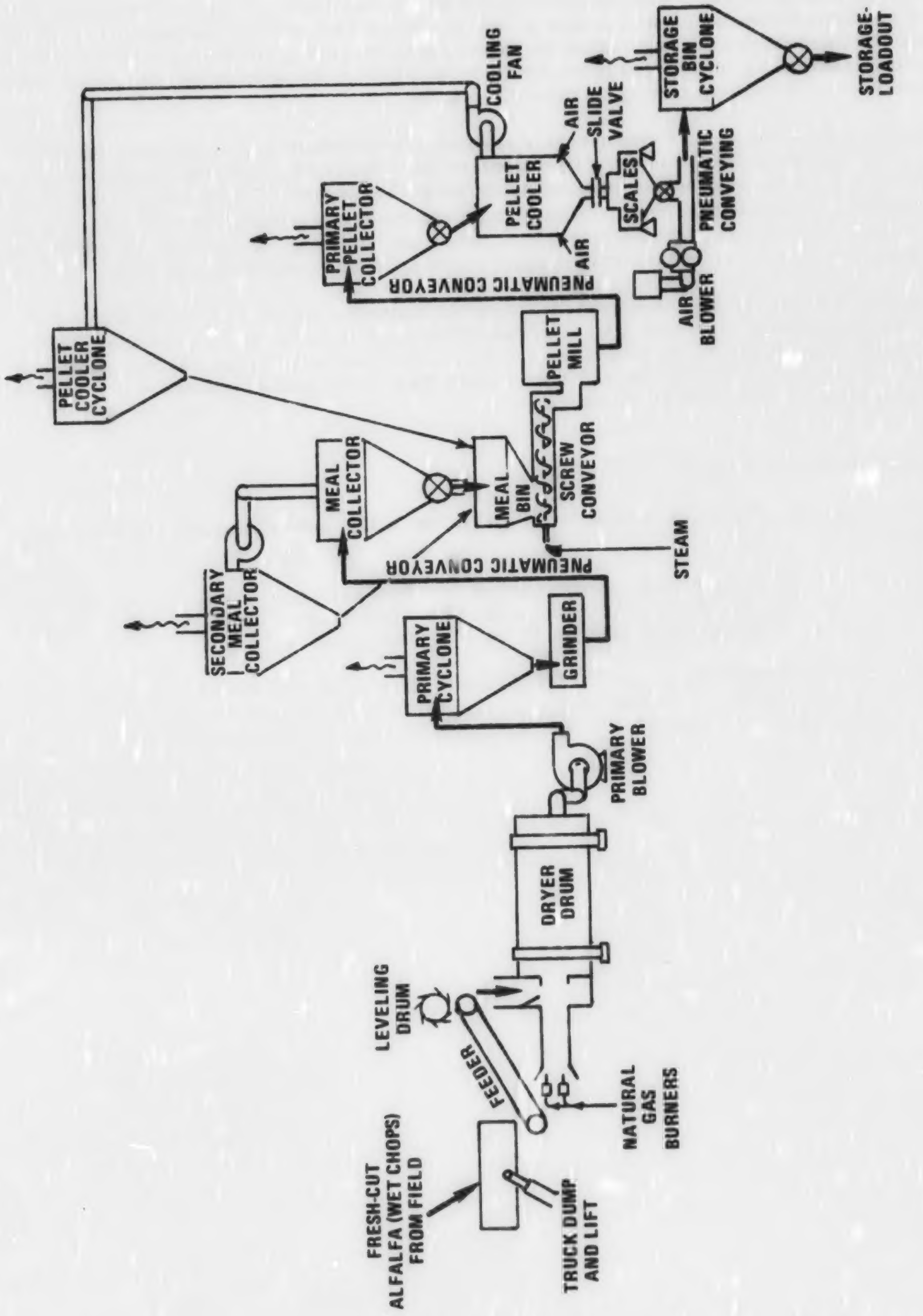
FRESH-CUT ALFALFA (WET CHOPS) FROM FIELD
TRUCK DUMP AND LIFT
FEEDER
LEVELING DRUM
NATURAL GAS BURNERS
DRYER DRUM
PRIMARY BLOWER
PRIMARY CYCLONE
GRINDER
SECONDARY MEAL COLLECTOR
PNEUMATIC CONVEYOR
MEAL COLLECTOR
MEAL BIN
SCREW CONVEYOR
STEAM
PELLET COOLER CYCLONE
PELLET MILL
PNEUMATIC CONVEYOR
PRIMARY PELLET COLLECTOR
PELLET COOLER
AIR
AIR
COOLING FAN
SLIDE VALVE
SCALES
AIR BLOWER
PNEUMATIC CONVEYING
STORAGE BIN CYCLONE
STORAGE-LOADOUT

Figure 6.1-1. Generalized flow diagram for alfalfa dehydration plant.

Equipment modification provides another means of particulate control. Existing cyclones can be replaced with more efficient cyclones and concomitant air flow systems. In addition, the furnace and burners can be modified or replaced to minimize flame impingement on the incoming green chops. In plants where the hammermill is a production bottleneck, a tendency exists to overdry the chops to increase throughput, which results in increased emissions. Adequate hammermill capacity can reduce this practice.

Secondary control devices can be employed on the cyclone collector exhaust streams. Generally, this practice has been limited to the installation of secondary cyclones or fabric filters on the meal collector, pellet collector, or pellet cooler cyclones. Some measure of secondary control can also be effected on these cyclones by ducting their exhaust streams back into the primary cyclone. Primary cyclones are not controlled by fabric filters because of the high moisture content in the resulting exhaust stream. Medium energy wet scrubbers are effective in reducing particulate emissions from the primary cyclones, but have only been installed at a few plants.

Some plants employ cyclone effluent recycle systems for particulate control. One system skims off the particulate-laden portion of the primary cyclone exhaust and returns it to the furnace for incineration. Another system recycles a large portion of the meal collector cyclone exhaust back to the hammermill. Both systems can be effective in controlling particulates but may result in operating problems, such as condensation in the recycle lines and plugging or overheating of the hammermill.

References for Section 6.1

1. Source information supplied by Ken Smith of the American Dehydrators Association, Mission, Kan. December 1975.

2. Gorman, P.G. et al. Emission Factor Development for the Feed and Grain Industry. Midwest Research Institute. Kansas City, Mo. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. 68-02-1324. Publication No. EPA-450/3-75-054. October 1974.

3. Smith, K.D. Particulate Emissions from Alfalfa Dehydrating Plants - Control Costs and Effectiveness. Final Report. American Dehydrators Association. Mission, Kan. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. Grant No. R801446. Publication No. 650/2-74-007. January 1974.

6.2 COFFEE ROASTING

6.2.1 Process Description[1,2]

Coffee, which is imported in the form of green beans, must be cleaned, blended, roasted, and packaged before being sold. In a typical coffee roasting operation, the green coffee beans are freed of dust and chaff by dropping the beans into a current of air. The cleaned beans are then sent to a batch or continuous roaster. During the roasting, moisture is driven off, the beans swell, and chemical changes take place that give the roasted beans their typical color and aroma. When the beans have reached a certain color, they are quenched, cooled, and stoned.

6.2.2 Emissions[1,2]

Dust, chaff, coffee bean oils (as mists), smoke, and odors are the principal air contaminants emitted from coffee processing. The major source of particulate emissions and practically the only source of aldehydes, nitrogen oxides, and organic acids is the roasting process. In a direct-fired roaster, gases are vented without recirculation through the flame. In the indirect-fired roaster, however, a portion of the roaster gases are recirculated and particulate emissions are reduced. Emissions of both smoke and odors from the roasters can be almost completely removed by a properly designed afterburner.[1,2]

Particulate emissions also occur from the stoner and cooler. In the stoner, contaminating materials heavier than the roasted beans are separated from the beans by an air stream. In the cooler, quenching the hot roasted beans with water causes emissions of large quantities of steam and some particulate matter.[3] Table 6.2-1 summarizes emissions from the various operations involved in coffee processing.

Table 6.2-1. EMISSION FACTORS FOR ROASTING PROCESSES WITHOUT CONTROLS
EMISSION FACTOR RATING: B

Type of process	Pollutant							
	Particulates[a]		NO_x[b]		Aldehydes[b]		Organic acids[b]	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Roaster								
Direct-fired	7.6	3.8	0.1	0.05	0.2	0.1	0.9	0.45
Indirect-fired	4.2	2.1	0.1	0.05	0.2	0.1	0.9	0.45
Stoner and cooler[c]	1.4	0.7	–	–	–	–	–	–
Instant coffee spray dryer	1.4[d]	0.7[d]	–	–	–	–	–	–

[a] Reference 3.

[b] Reference 1.

[c] If cyclone is used, emissions can be reduced by 70 percent.

[d] Cyclone plus wet scrubber always used, representing a controlled factor.

References for Section 6.2

1. Polglase, W.L., H.F. Dey, and R.T. Walsh. Coffee Processing. In: Air Pollution Engineering Manual. Danielson, J.A. (ed.). U.S. DHEW, PHS, National Center for Air Pollution Control. Cincinnati, Ohio. Publication Number 999-AP-40. 1967. p. 746-749.

2. Duprey, R.L. Compilation of Air Pollutant Emission Factors. U.S. DHEW, PHS, National Center for Air Pollution Control. Durham, N.C. PHS Publication Number 999-AP-42. 1968. p. 19-20.

3. Partee, F. Air Pollution in the Coffee Roasting Industry. Revised Ed. U.S. DHEW, PHS, Division of Air Pollution. Cincinnati, Ohio. Publication Number 999-AP-9. 1966.

6.3 COTTON GINNING

6.3.1 General[1]

The primary function of a cotton gin is to take raw seed cotton and separate the seed and the lint. A large amount of trash is found in the seed cotton, and it must also be removed. The problem of collecting and disposing of gin trash is two-fold. The first problem consists of collecting the coarse, heavier trash such as burrs, sticks, stems, leaves, sand, and dirt. The second problem consists of collecting the finer dust, small leaf particles, and fly lint that are discharged from the lint after the fibers are removed from the seed. From 1 ton (0.907 MT) of seed cotton, approximately one 500-pound (226-kilogram) bale of cotton can be made.

6.3.2 Emissions and Controls

The major sources of particulates from cotton ginning include the unloading fan, the cleaner, and the stick and burr machine. From the cleaner and stick and burr machine, a large percentage of the particles settle out in the plant, and an attempt has been made in Table 6.3-1 to present emission factors that take this into consideration. Where cyclone collectors are used, emissions have been reported to be about 90 percent less.[1]

Table 6.3-1. EMISSION FACTORS FOR COTTON GINNING OPERATIONS WITHOUT CONTROLS[a,b]
EMISSION FACTOR RATING: C

Process	Estimated total particulates		Particles > 100 μm settled out, %	Estimated emission factor (released to atmosphere)	
	lb/bale	kg/bale		lb/bale	kg/bale
Unloading fan	5	2.27	0	5.0	2.27
Cleaner	1	0.45	70	0.30	0.14
Stick and burr machine	3	1.36	95	0.20	0.09
Miscellaneous	3	1.36	50	1.5	0.68
Total	12	5.44	–	7.0	3.2

[a] References 1 and 2.

[b] One bale weighs 500 pounds (226 kilograms).

References for Section 6.3

1. Air-Borne Particulate Emissions from Cotton Ginning Operations. U.S. DHEW, PHS, Taft Sanitary Engineering Center. Cincinnati, Ohio. 1960.

2. Control and Disposal of Cotton Ginning Wastes. A Symposium Sponsored by National Center for Air Pollution Control and Agricultural Research Service, Dallas, Texas. May 1966.

6.4 FEED AND GRAIN MILLS AND ELEVATORS

6.4.1 General[1-3]

Grain elevators are buildings in which grains are gathered, stored, and discharged for use, further processing, or shipping. They are classified as "country," "terminal," and "export" elevators, according to their purpose and location. At country elevators, grains are unloaded, weighed, and placed in storage as they are received from farmers residing within about a 20-mile radius of the elevator. In addition, country elevators sometimes dry or clean grain before it is shipped to terminal elevators or processors.

Terminal elevators receive most of their grain from country elevators and ship to processors, other terminals, and exporters. The primary functions of terminal elevators are to store large quantities of grain without deterioration and to dry, clean, sort, and blend different grades of grain to meet buyer specifications.

Export elevators are similar to terminal elevators except that they mainly load grain on ships for export.

Processing of grain in mills and feed plants ranges from very simple mixing steps to complex industrial processes. Included are such diverse processes as: (1) simple mixing operations in feed mills, (2) grain milling in flour mills, (3) solvent extracting in soybean processing plants, and (4) a complex series of processing steps in a corn wet-milling plant.

6.4.2 Emissions and Controls

Grain handling, milling, and processing include a variety of operations from the initial receipt of the grain at either a country or terminal elevator to the delivery of a finished product. Flour, livestock feed, soybean oil, and corn syrup are among the products produced from plants in the grain and feed industry. Emissions from the feed and grain industry can be separated into two general areas, those occurring at grain elevators and those occurring at grain processing operations.

6.4.2.1 Grain Elevators - Grain elevator emissions can occur from many different operations in the elevator including unloading (receiving), loading (shipping), drying, cleaning, headhouse (legs), tunnel belt, gallery belt, and belt trippers. Emission factors for these operations at terminal, country, and export elevators are presented in Table 6.4-1. All of these emission factors are approximate average values intended to reflect a variety of grain types. Actual emission factors for a specific source may be considerably different, depending on the type of grain, i.e., corn, soybeans, wheat, and other factors such as grain quality.

The emission factors shown in Table 6.4-1 represent the amount of dust generated per ton of grain processed through each of the designated operations (i.e., uncontrolled emission factors). Amounts of grain processed through each of these operations in a given elevator are dependent on such factors as the amount of grain turned (interbin transfer), amount dryed, and amount cleaned, etc. Because the amount of grain passing through each operation is often difficult to determine, it may be more useful to express the emission factors in terms of the amount of grain shipped or received, assuming these amounts are about the same over the long term. Emission factors from Table 6.4-1 have been modified accordingly and are shown in Table 6.4-2 along with the appropriate multiplier that was used as representative of typical ratios of throughput at each operation to the amount of grain shipped or received. This ratio is an approximate value based on average values for turning, cleaning, and drying in each

type of elevator. However, because operating practices in individual elevators are different, these ratios, like the basic emission factors themselves, are more valid when applied to a group of elevators rather than individual elevators.

Table 6.4-1. PARTICULATE EMISSION FACTORS FOR UNCONTROLLED GRAIN ELEVATORS
EMISSION FACTOR RATING: B

Type of source	Emission factor[a]	
	lb/ton	kg/MT
Terminal elevators		
Unloaded (receiving)	1.0	0.5
Loading (shipping)	0.3	0.2
Removal from bins (tunnel belt)	1.4	1.7
Drying[b]	1.1	0.6
Cleaning[c]	3.0	1.5
Headhouse (legs)	1.5	0.8
Tripper (gallery belt)	1.0	0.5
Country elevators		
Unloading (receiving)	0.6	0.3
Loading (shipping)	0.3	0.2
Removal from bins	1.0	0.5
Drying[b]	0.7	0.4
Cleaning[c]	3.0	1.5
Headhouse (legs)	1.5	0.8
Export elevators		
Unloading (receiving)	1.0	0.5
Loading (shipping)	1.0	0.5
Removal from bins (tunnel belt)	1.4	0.7
Drying[b]	1.1	0.5
Cleaning[c]	3.0	1.5
Headhouse (legs)	1.5	0.8
Tripper (gallery belts)	1.0	0.5

[a] Emission factors are in terms of pounds of dust emitted per ton of grain processed by each operation. Most of the factors for terminal and export elevators are based on Reference 1. Emission factors for drying are based on References 2 and 3. The emission factors for country elevators are based on Reference 1 and specific country elevator test data in References 4 through 9.

[b] Emission factors for drying are based on 1.8 lb/ton for rack dryers and 0.3 lb/ton for column dryers prorated on the basis of distribution of these two types of dryers in each elevator category, as discussed in Reference 3.

[c] Emission factor of 3.0 for cleaning is an average value which may range from <0.5 for wheat up to 6.0 for corn.

The factors in Tables 6.4-1 or 6.4-2 should not be added together in an attempt to obtain a single emission factor value for grain elevators because in most elevators some of the operations are equipped with control devices and some are not. Therefore, any estimation of emissions must be directed to each operation and its associated control device, rather than the elevator as a whole, unless the purpose was to estimate total potential (i.e., uncontrolled) emissions. An example of the use of emission factors in making an emission inventory is contained in Reference 3.

Table 6.4-2. PARTICULATE EMISSION FACTORS FOR GRAIN ELEVATORS BASED ON AMOUNT OF GRAIN RECEIVED OR SHIPPED[a]

Type of source	Emission factor, lb/ton processed	×	Typical ratio of tons processed to tons received or shipped[d]	=	Emission factor, lb/ton received or shipped
Terminal elevators					
Unloading (receiving)	1.0		1.0		1.0
Loading (shipping)	0.3		1.0		0.3
Removal from bins (tunnel belt)	1.4		2.0		2.8
Drying[b]	1.1		0.1		0.1
Cleaning[c]	3.0		0.2		0.6
Headhouse (legs)	1.5		3.0		4.5
Tripper (gallery belt)	1.0		1.7		1.7
Country elevators					
Unloading (receiving)	0.6		1.0		0.6
Loading (shipping)	0.3		1.0		0.3
Removal from bins	1.0		2.1		2.1
Drying[b]	0.7		0.3		0.2
Cleaning[c]	3.0		0.1		0.3
Headhouse (legs)	1.5		3.1		4.7
Export elevators					
Unloading (receiving)	1.0		1.0		1.0
Loading (shipping)	1.0		1.0		1.0
Removal from bins (tunnel belt)	1.4		1.2		1.7
Drying[b]	1.1		0.01		0.01
Cleaning[c]	3.0		0.2		0.6
Headhouse (legs)	1.5		2.2		3.3
Tripper (gallery belt)	1.0		1.1		1.1

[a] Assume that over the long term the amount received is approximately equal to amount shipped.

[b] See Note[b] in Table 3.4-1.

[c] See Note[c] in Table 6.4-1.

[d] Ratios shown are average values taken from a survey of many elevators across the U.S.[3] These ratios can be considerably different for any individual elevator or group of elevators in the same locale.

Some of the operations listed in the table, such as the tunnel belt and belt tripper, are internal or in-house dust sources which, if uncontrolled, might show lower than expected atmospheric emissions because of internal settling of dust. The reduction in emissions via internal settling is not known, although it is possible that all of this dust is eventually emitted to the atmosphere due to subsequent external operations, internal ventilation, or other means.

Many elevators utilize control devices on at least some operations. In the past, cyclones have commonly been applied to legs in the headhouse and tunnel belt hooding systems. More recently, fabric filters have been utilized at many elevators on almost all types of operations. Unfortunately, some sources in grain elevators present control problems. Control of loadout operations is difficult because of the problem of containment of the emissions. Probably the most difficult operation to control, because of the large flow rate and high moisture content of the exhaust gases, is the dryers. Screenhouses or continuously vacuumed screen systems are available for reducing dryer emissions and have been applied at several facilities. Detailed descriptions of dust control systems for grain elevator operations are contained in Reference 2.

6.4.2.2 Grain Processing Operations - Grain processing operations include many of the operations performed in a grain elevator in addition to milling and processing of the grain. Emission factors for different grain milling and processing operations are presented in Table 6.4-3. Brief discussions of these different operations and the methods used for arriving at the emission factor values shown in Table 6.4-3 are presented below.

Table 6.4-3. PARTICULATE EMISSION FACTORS FOR GRAIN PROCESSING OPERATIONS[1,2,3]

EMISSION FACTOR RATING: D

Type of source	Emission factor[a,b] (uncontrolled except where indicated)	
	lb/ton	kg/MT
Feed mills		
Receiving	1.30	0.65
Shipping	0.50	0.25
Handling	3.00	1.50
Grinding	0.10[c]	0.05[c]
Pellet coolers	0.10[c]	0.05[c]
Wheat mills		
Receiving	1.00	0.50
Precleaning and handling	5.00	2.50
Cleaning house	-	-
Millhouse	70.00	35.00
Durum mills		
Receiving	1.00	0.50
Precleaning and handling	5.00	2.50
Cleaning house	-	-
Millhouse	-	-
Rye milling		
Receiving	1.00	0.50
Precleaning and handling	5.00	2.50
Cleaning house	-	-
Millhouse	70.00	35.00
Dry corn milling		
Receiving	1.00	0.50
Drying	0.50	0.25
Precleaning and handling	5.00	2.50
Cleaning house	6.00	3.00
Degerming and milling	-	-
Oat milling		
Total	2.50[d]	1.25[d]
Rice milling		
Receiving	0.64	0.32
Handling and precleaning	5.00	2.50
Drying		-
Cleaning and millhouse		-
Soybean mills		
Receiving	1.60	0.80
Handling	5.00	2.50
Cleaning	-	-
Drying	7.20	3.60
Cracking and dehulling	3.30	1.65
Hull grinding	2.00	1.00

Table 6.4-3 (continued). PARTICULATE EMISSION FACTORS FOR GRAIN PROCESSING OPERATIONS[1,2,3]
EMISSION FACTOR RATING: D

Type of source	Emission factor[a,b] (uncontrolled except where indicated)	
	lb/ton	kg/MT
Bean conditioning	0.10	0.05
Flaking	0.57	0.29
Meal dryer	1.50	0.75
Meal cooler	1.80	0.90
Bulk loading	0.27	0.14
Corn wet milling		
Receiving	1.00	0.50
Handling	5.00	2.50
Cleaning	6.00	3.00
Dryers	-	-
Bulk loading	-	-

[a] Emission factors are expressed in terms of pounds of dust emitted per ton of grain entering the plant (i.e., received), which is not necessarily the same as the amount of material processed by each operation.

[b] Blanks indicate insufficient information.

[c] Controlled emission factor (controlled with cyclones).

[d] Controlled emission factor.(This represents several sources in one plant; some controlled with cyclones and others controlled with fabric filters.)

Emission factor data for feed mill operations are sparse. This is partly due to the fact that many ingredients, whole grain and other dusty materials (bran, dehydrated alfalfa, etc.), are received by both truck and rail and several unloading methods are employed. However, because some feed mill operations (handling, shipping, and receiving) are similar to operations in a grain elevator, an emission factor for each of these different operations was estimated on that basis. The remaining operations are based on information in Reference 2.

Three emission areas for wheat mill processing operations are grain receiving and handling, cleaning house, and milling operations. Data from Reference 1 are used to estimate emissions factors for grain receiving and handling. Data for the cleaning house are insufficient to estimate an emission factor, and information contained in Reference 2 is used to estimate the emission factor for milling operations. The large emission factor for the milling operation is somewhat misleading because almost all of the sources involved are equipped with control devices to prevent product losses; fabric filters are widely used for this purpose.

Operations for durum mills and rye milling are similar to those of wheat milling. Therefore, most of these emission factors are assumed equal to those for wheat mill operations.

The grain unloading, handling, and cleaning operations for dry corn milling are similar to those in other grain mills, but the subsequent operations are somewhat different. Also, some drying of corn received at the mill may be necessary prior to storage. An estimate of the emission factor for drying is obtained from Reference 2. Insufficient information is available to estimate emission factors for degerming and milling.

Information necessary to estimate emissions from oat milling is unavailable, and no emission factor for another grain is considered applicable because oats are reported to be dustier than many other grains. The only emission factor data available are for controlled emissions.[3] An overall controlled emission factor of 2.5 lb/ton is calculated from these data.

Emission factors for rice milling are based on those for similar operations in other grain handling facilities. Insufficient information is available to estimate emission factors for drying, cleaning, and mill house operations.

Information contained in Reference 2 is used to estimate emission factors for soybean mills.

Emissions information on corn wet-milling is unavailable in most cases due to the wide variety of products and the diversity of operations. Receiving, handling, and cleaning operations emission factors are assumed to be similar to those for dry corn milling.

Many of the operations performed in grain milling and processing plants are the same as those in grain elevators, so the control methods are similar. As in the case of grain elevators, these plants often use cyclones or fabric filters to control emissions from the grain handling operations (e.g., unloading, legs, cleaners, etc.). These same devices are also often used to control emissions from other processing operations; a good example of this is the extensive use of fabric filters in flour mills. However, there are also certain operations within some milling operations that are not amenable to use of these devices. Therefore, wet scrubbers have found some application, particularly where the effluent gas stream has a high moisture content. Certain other operations have been found to be especially difficult to control, such as rotary dryers in wet corn mills. Descriptions of the emission control systems that have been applied to operations within the grain milling and processing industries are contained in Reference 2.

This section was prepared for EPA by Midwest Research Institute.[10]

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2. Shannon, L.J. et al. Emission Control in the Grain and Feed Industry, Volume I - Engineering and Cost Study. Final Report. Prepared for Environmental Protection Agency by Midwest Research Institute. Document No. EPA-450/3-73-003a. Research Triangle Park, N.C. December 1973.

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6. Belgea, F.J. Cyclone Emissions and Efficiency Evaluation. Report submitted to North Dakota State Department of Health on tests at an elevator in Edenburg, North Dakota, by Pollution Curbs, Inc. St. Paul, Minnesota. March 10, 1972.

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258<

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6.5 FERMENTATION

6.5.1 Process Description[1]

For the purpose of this report only the fermentation industries associated with food will be considered. This includes the production of beer, whiskey, and wine.

The manufacturing process for each of these is similar. The four main brewing production stages and their respective sub-stages are: (1) brewhouse operations, which include (a) malting of the barley, (b) addition of adjuncts (corn, grits, and rice) to barley mash, (c) conversion of starch in barley and adjuncts to maltose sugar by enzymatic processes, (d) separation of wort from grain by straining, and (e) hopping and boiling of the wort; (2) fermentation, which includes (a) cooling of the wort, (b) additional yeast cultures, (c) fermentation for 7 to 10 days, (d) removal of settled yeast, and (e) filtration and carbonation; (3) aging, which lasts from 1 to 2 months under refrigeration; and (4) packaging, which includes (a) bottling-pasteurization, and (b) racking draft beer.

The major differences between beer production and whiskey production are the purification and distillation necessary to obtain distilled liquors and the longer period of aging. The primary difference between wine making and beer making is that grapes are used as the initial raw material in wine rather than grains.

6.5.2 Emissions[1]

Emissions from fermentation processes are nearly all gases and primarily consist of carbon dioxide, hydrogen, oxygen, and water vapor, none of which present an air pollution problem. Emissions of particulates, however, can occur in the handling of the grain for the manufacture of beer and whiskey. Gaseous hydrocarbons are also emitted from the drying of spent grains and yeast in beer and from the whiskey-aging warehouses. No significant emissions have been reported for the production of wine. Emission factors for the various operations associated with beer, wine, and whiskey production are shown in Table 6.5-1.

Table 6.5-1. EMISSION FACTORS FOR FERMENTATION PROCESSES
EMISSION FACTOR RATING: E

Type of product	Particulates		Hydrocarbons	
	lb/ton	kg/MT	lb/ton	kg/MT
Beer				
Grain handling[a]	3	1.5	–	–
Drying spent grains, etc.[a]	5	2.5	NA[b]	NA
Whiskey				
Grain handling[a]	3	1.5	–	–
Drying spent grains, etc.[a]	5	2.5	NA	NA
Aging	–	–	10[c]	0.024[d]
Wine	Neg[e]	Neg	Neg[e]	Neg

[a] Based on section on grain processing.
[b] No emission factor available, but emissions do occur.
[c] Pounds per year per barrel of whiskey stored.[2]
[d] Kilograms per year per liter of whiskey stored.
[e] No significant emissions.

References for Section 6.5

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6.6 FISH PROCESSING

revised by Susan Sercer

6.6.1 Process Description

Fish processing includes the canning of fish and the manufacturing of by-products such as fish oil and fish meal. The manufacturing of fish oil and fish meal are known as reduction processes. A generalized fish processing operation is presented in Figure 6.6-1 .

Two types of canning operations are used. One is the "wet fish" method in which trimmed and eviscerated fish are cooked directly in open cans. The other operation is the "pre-cooked" process in which eviscerated fish are cooked whole and portions are hand selected and packed into cans. The pre-cooked process is used primarily for larger fish such as tuna.

By-product manufacture of rejected whole fish and scrap requires several steps. First, the fish scrap mixture from the canning line is charged to a live steam cooker. After the material leaves the cooker, it is pressed to remove water and oil. The resulting press cake is broken up and dried in a rotary drier.

Two types of driers are used to dry the press cake: direct-fired and steam-tube driers. Direct-fired driers contain a stationary firebox ahead of the rotating section. The hot products of combustion from the firebox are mixed with air and wet meal inside the rotating section of the drier. Exhaust gases are generally vented to a cyclone separator to recover much of the entrained fish meal product. Steam-tube driers contain a cylindrical bank of rotating tubes through which hot, pressurized steam is passed. Heat is indirectly transferred to the meal and the air from the hot tubes. As with direct-fired driers, the exhaust gases are vented to a cyclone for product recovery.

6.6.2 Emissions and Controls

Although smoke and dust can be a problem, odors are the most objectionable emissions from fish processing plants. By-product manufacture results in more of these odorous contaminants than cannery operations because of the greater state of decomposition of the materials processed. In general, highly decayed feedstocks produce greater concentrations of odors than do fresh feedstocks.

The largest odor sources are the fish meal driers. Usually, direct-fired driers emit more odors than steam-tube driers. Direct-fired driers will also emit smoke, particularly if the driers are operated under high temperature conditions. Cyclones are frequently employed on drier exhaust gases for product recovery and particulate emission control.

Odorous gases from reduction cookers consist primarily of hydrogen sulfide [H_2S] and trimethylamine [$(CH_3)_3N$]. Odors from reduction cookers are emitted in volumes appreciably less than from fish meal driers. There are virtually no particulate emissions from reduction cookers.

Some odors are also produced by the canning processes. Generally, the pre-cooked process emits less odorous gases than the wet-fish process. This is because in the pre-cooked process, the odorous exhaust gases are trapped in the cookers, whereas in the wet-fish process, the steam and odorous offgases are commonly vented directly to the atmosphere.

Fish cannery and fish reduction odors can be controlled with afterburners, chlorinator-scrubbers, and condensers. Afterburners are most effective, providing virtually 100 percent odor control; however they are costly from a fuel-use standpoint. Chlorinator-scrubbers have been found to be 95 to 99 percent effective in controlling odors from cookers and driers. Condensers are the least effective control device. Generally, centrifugal collectors are satisfactory for controlling excessive dust emissions from driers.

Emission factors for fish processing are presented in Table 6.6-1.

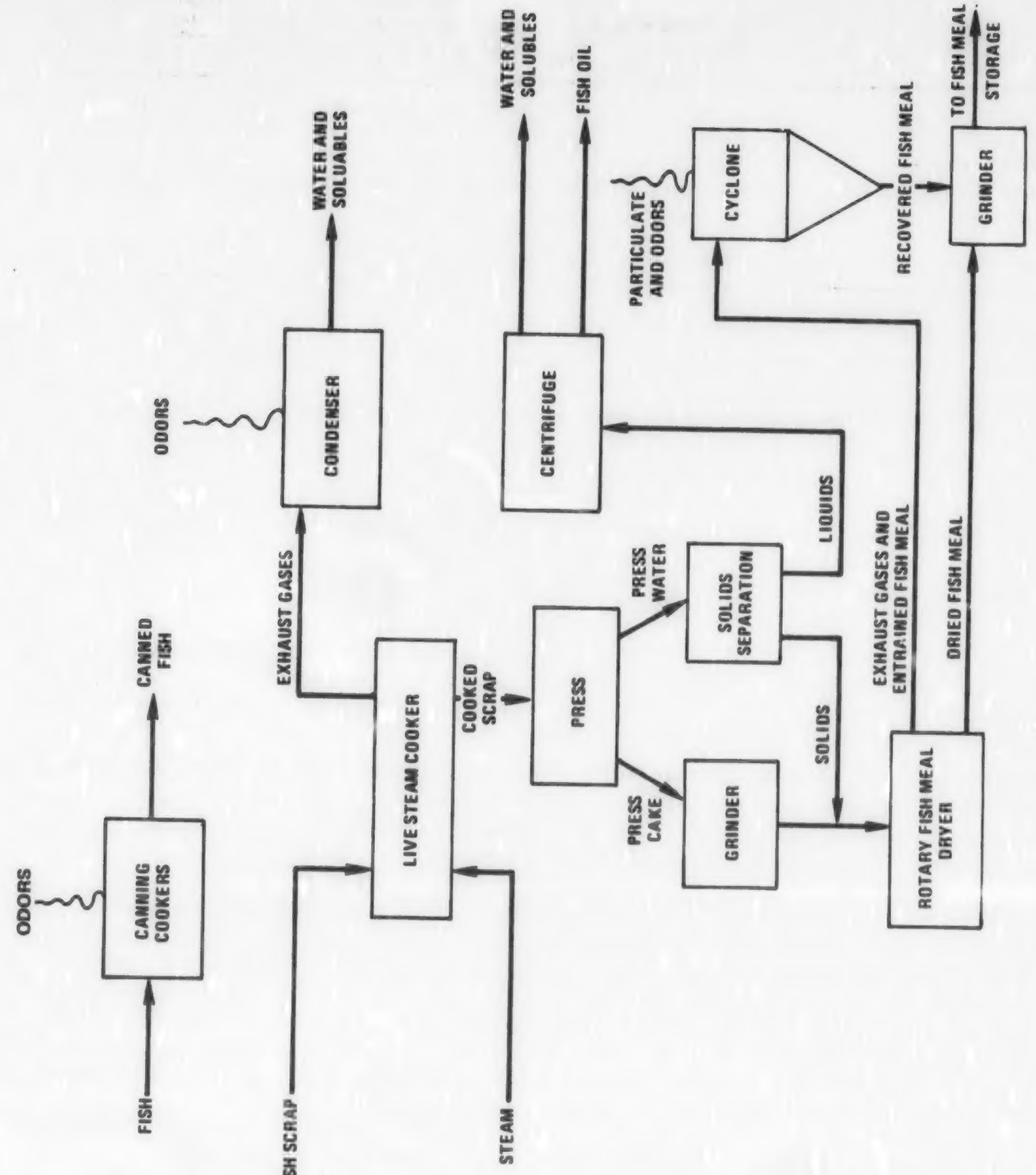
ODORS
CANNING COOKERS
FISH
CANNED FISH
FISH SCRAP
STEAM
LIVE STEAM COOKER
EXHAUST GASES
ODORS
CONDENSER
WATER AND SOLUABLES
COOKED SCRAP
PRESS
PRESS CAKE
PRESS WATER
GRINDER
SOLIDS SEPARATION
SOLIDS
LIQUIDS
CENTRIFUGE
WATER AND SOLUBLES
FISH OIL
ROTARY FISH MEAL DRYER
EXHAUST GASES AND ENTRAINED FISH MEAL
DRIED FISH MEAL
PARTICULATE AND ODORS
CYCLONE
RECOVERED FISH MEAL
GRINDER
TO FISH MEAL STORAGE

Figure 6.6-1. A generalized fish processing flow diagram.

Table 6.6-1. EMISSION FACTORS FOR FISH PROCESSING PLANTS
EMISSION FACTOR RATING: C

Emission source	Particulates		Trimethylamine $(CH_3)_3N$		Hydrogen sulfide (H_2S)	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Cookers, canning	Neg.[a]	Neg.[a]	NA[b]	NA[b]	NA[b]	NA[b]
Cookers, fish scrap						
Fresh fish	Neg.[a]	Neg.[a]	0.3[c]	0.15[c]	0.01[c]	0.005[c]
Stale fish	Neg.[a]	Neg.[a]	3.5[c]	1.75[c]	0.2[c]	0.10[c]
Dryers	0.1[d]	0.05[d]	NA[d]	NA[d]	NA[d]	NA[d]

[a] Reference 1.

[b] Although it is known that odors are emitted from canning cookers, quantitative estimates are not available.

[c] Reference 2.

[d] Limited data suggest that there is not much difference in particulate emissions between steam tube and direct-fired dryers. Based on reference 1.

References for Section 6.6

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2. Summer, W. Methods of Air Deodorization. New York, Elsevier Publishing Company. 1963. p. 284-286.

6.7 MEAT SMOKEHOUSES

6.7.1 Process Description[1]

Smoking is a diffusion process in which food products are exposed to an atmosphere of hardwood smoke, causing various organic compounds to be absorbed by the food. Smoke is produced commerically in the United States by three major methods: (1) by burning dampened sawdust (20 to 40 percent moisture), (2) by burning dry sawdust (5 to 9 percent moisture) continuously, and (3) by friction. Burning dampened sawdust and kiln-dried sawdust are the most widely used methods. Most large, modern, production meat smokehouses are the recirculating type, in which smoke is circulated at reasonably high temperatures throughout the smokehouse.

6.7.2 Emissions and Controls[1]

Emissions from smokehouses are generated from the burning hardwood rather than from the cooked product itself. Based on approximately 110 pounds of meat smoked per pound of wood burned (110 kilograms of meat per kilogram of wood burned), emission factors have been derived for meat smoking and are presented in Table 6.7-1.

Emissions from meat smoking are dependent on several factors, including the type of wood, the type of smoke generator, the moisture content of the wood, the air supply, and the amount of smoke recirculated. Both low-voltage electrostatic precipitators and direct-fired afterburners may be used to reduce particulate and organic emissions. These controlled emission factors have also been shown in Table 6.7-1.

Table 6.7-1. EMISSION FACTORS FOR MEAT SMOKING[a,b]
EMISSION FACTOR RATING: D

Pollutant	Uncontrolled		Controlled[c]	
	lb/ton of meat	kg/MT of meat	lb/ton of meat	kg/MT of meat
Particulates	0.3	0.15	0.1	0.05
Carbon monoxide	0.6	0.3	Neg[d]	Neg
Hydrocarbons (CH$_4$)	0.07	0.035	Neg	Neg
Aldehydes (HCHO)	0.08	0.04	0.05	0.025
Organic acids (acetic)	0.2	0.10	0.1	0.05

[a] Based on 110 pounds of meat smoked per pound of wood burned (110 kg meat/kg wood burned).
[b] References 2, 3, and section on charcoal production.
[c] Controls consist of either a wet collector and low-voltage precipitator in series or a direct-fired afterburner.
[d] With afterburner.

References for Section 6.7

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6.8 NITRATE FERTILIZERS

6.8.1 General[1,2]

For this report, nitrate fertilizers are defined as the product resulting from the reaction of nitric acid and ammonia to form ammonium nitrate solutions or granules. Essentially three steps are involved in producing ammonium nitrate: neutralization, evaporation of the neutralized solution, and control of the particle size and characteristics of the dry product.

Anhydrous ammonia and nitric acid (57 to 65 percent HNO_3)[3,4] are brought together in the neutralizer to produce ammonium nitrate. An evaporator or concentrator is then used to increase the ammonium nitrate concentration. The resulting solutions may be formed into granules by the use of prilling towers or by ordinary granulators. Limestone may be added in either process in order to produce calcium ammonium nitrate.[5,6]

6.8.2 Emissions and Controls

The main emissions from the manufacture of nitrate fertilizers occur in the neutralization and drying operations. By keeping the neutralization process on the acidic side, losses of ammonia and nitric oxides are kept at a minimum. Nitrate dust or particulate matter is produced in the granulation or prilling operation. Particulate matter is also produced in the drying, cooling, coating, and material handling operations. Additional dust may escape from the bagging and shipping facilities.

Typical operations do not use collection devices on the prilling tower. Wet or dry cyclones, however, are used for various granulating, drying, or cooling operations in order to recover valuable products. Table 6.8-1 presents emission factors for the manufacture of nitrate fertilizers.

Table 6.8-1. EMISSION FACTORS FOR NITRATE FERTILIZER MANUFACTURING WITHOUT CONTROLS
EMISSION FACTOR RATING: B

Type of process[a]	Particulates		Nitrogen oxides (NO_3)		Ammonia	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
With prilling tower[b]						
Neutralizer[c,d]	–	–	–	–	2	1
Prilling tower	0.9	0.45	–	–	–	–
Dryers and coolers[e]	12	6	–	–	–	–
With granulator[b]						
Neutralizer[c,d]	–	–	–	–	2	1
Granulator[e]	0.4	0.2	0.9	0.45	0.5	0.25
Dryers and coolers[e,f]	7	3.5	3	1.5	1.3	0.65

[a] Plants will use either a prilling tower or a granulator but not both.
[b] Reference 7.
[c] Reference 8.
[d] Controlled factor based on 95 percent recovery in recycle scrubber.
[e] Use of wet cyclones can reduce emissions by 70 percent.
[f] Use of wet-screen scrubber following cyclone can reduce emissions by 95 to 97 percent.

References for Section 6.8

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6.9 ORCHARD HEATERS

by Dennis H. Ackerson

6.9.1 General[1-6]

Orchard heaters are commonly used in various areas of the United States to prevent frost damage to fruit and fruit trees. The five common types of orchard heaters—pipeline, lazy flame, return stack, cone, and solid fuel—are shown in Figure 6.9-1. The pipeline heater system is operated from a central control and fuel is distributed by a piping system from a centrally located tank. Lazy flame, return stack, and cone heaters contain integral fuel reservoirs, but can be converted to a pipeline system. Solid fuel heaters usually consist only of solid briquettes, which are placed on the ground and ignited.

The ambient temperature at which orchard heaters are required is determined primarily by the type of fruit and stage of maturity, by the daytime temperatures, and by the moisture content of the soil and air.

During a heavy thermal inversion, both convective and radiant heating methods are useful in preventing frost damage; there is little difference in the effectiveness of the various heaters. The temperature response for a given fuel rate is about the same for each type of heater as long as the heater is clean and does not leak. When there is little or no thermal inversion, radiant heat provided by pipeline, return stack, or cone heaters is the most effective method for preventing damage.

Proper location of the heaters is essential to the uniformity of the radiant heat distributed among the trees. Heaters are usually located in the center space between four trees and are staggered from one row to the next. Extra heaters are used on the borders of the orchard.

6.9.2 Emissions[1,6]

Emissions from orchard heaters are dependent on the fuel usage rate and the type of heater. Pipeline heaters have the lowest particulate emission rates of all orchard heaters. Hydrocarbon emissions are negligible in the pipeline heaters and in lazy flame, return stack, and cone heaters that have been converted to a pipeline system. Nearly all of the hydrocarbon losses are evaporative losses from fuel contained in the heater reservoir. Because of the low burning temperatures used, nitrogen oxide emissions are negligible.

Emission factors for the different types of orchard heaters are presented in Table 6.9-1 and Figure 6.9-2.

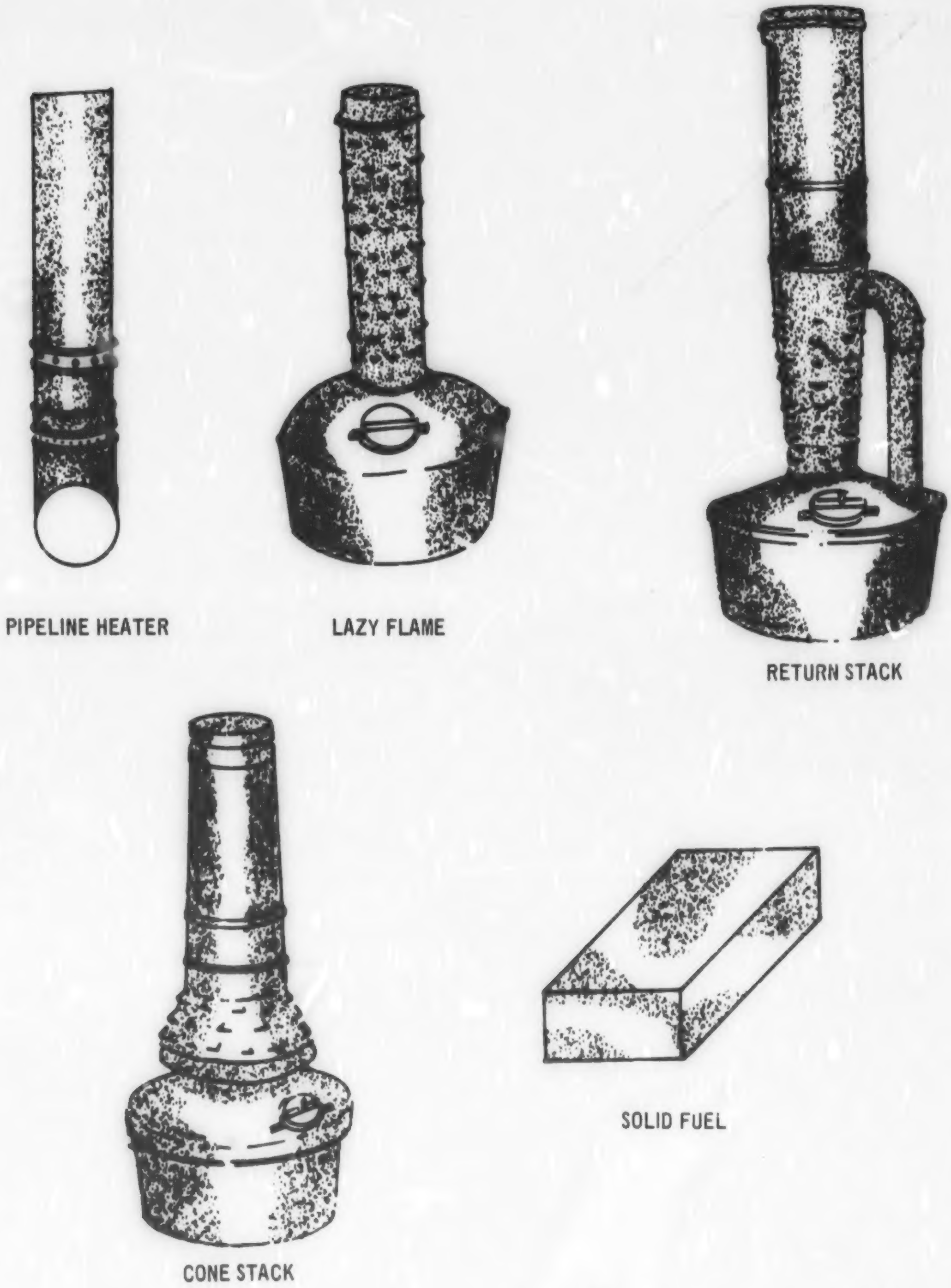
PIPELINE HEATER
LAZY FLAME
RETURN STACK
CONE STACK
SOLID FUEL

Figure 6.9-1. Types of orchard heaters.[6]

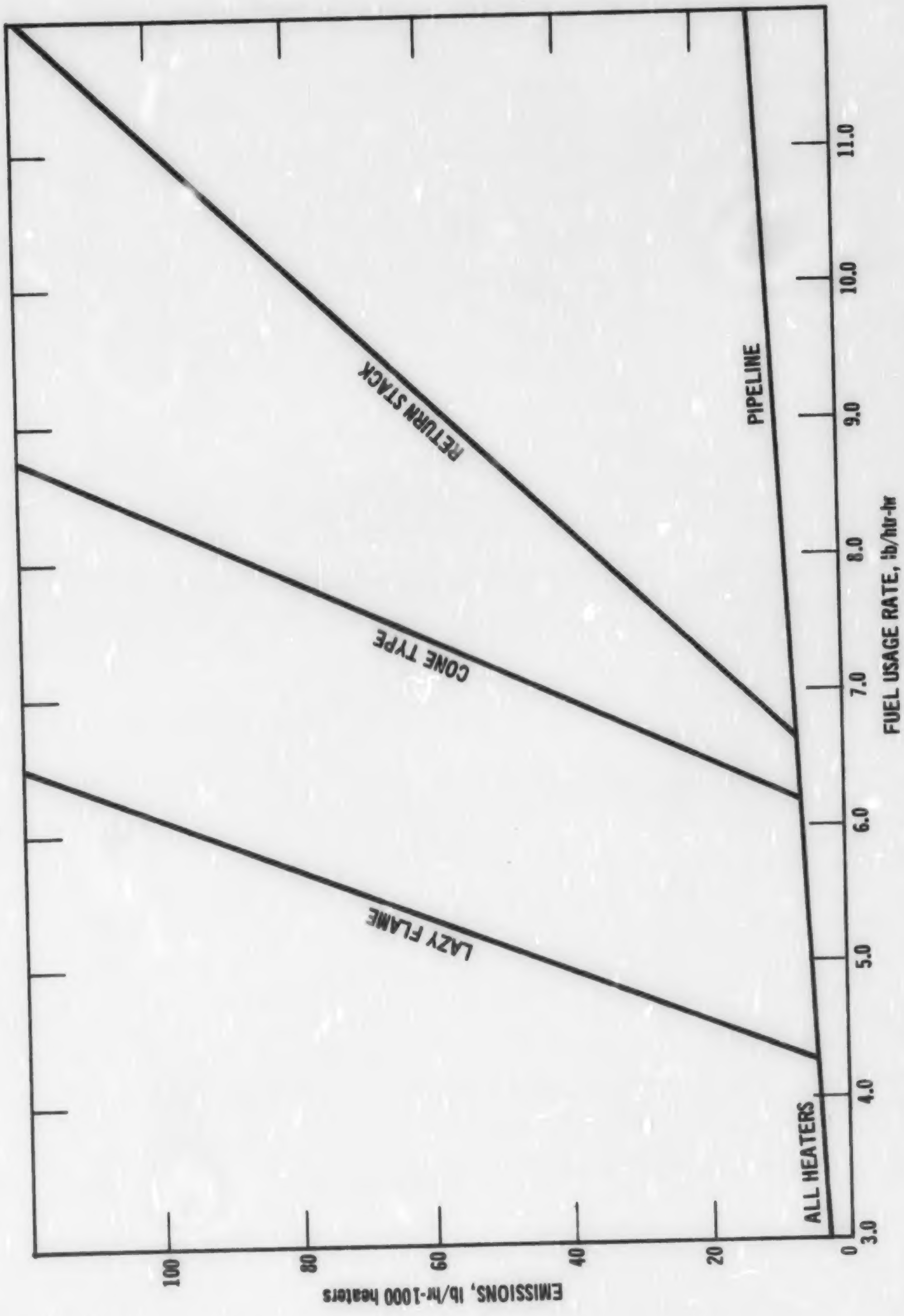

Figure 6.9-2. Particulate emissions from orchard heaters.3,6

Table 6.9-1. EMISSION FACTORS FOR ORCHARD HEATERS[a]
EMISSION FACTOR RATING: C

Pollutant	Type of heater				
	Pipeline	Lazy flame	Return stack	Cone	Solid fuel
Particulate					
lb/htr-hr	b	b	b	b	0.05
kg/htr-hr	b	b	b	b	0.023
Sulfur oxides					
lb/htr-hr	0.13S[d]	0.11S	0.14S	0.14S	NA[e]
kg/htr-hr	0.06S	0.05S	0.06S	0.06S	NA
Carbon monoxide					
lb/htr-hr	6.2	NA	NA	NA	NA
kg/htr-hr	2.8	NA	NA	NA	NA
Hydrocarbons[f]					
lb/htr-yr	Neg[g]	16.0	16.0	16.0	Neg
kg/htr-yr	Neg	7.3	7.3	7.3	Neg
Nitrogen oxides[h]					
lb/htr-hr	Neg	Neg	Neg	Neg	Neg
kg/htr-hr	Neg	Neg	Neg	Neg	Neg

[a] References 1, 3, 4, and 6.

[b] Particulate emissions for pipeline, lazy flame, return stack, and cone heaters are shown in Figure 6.9-2.

[c] Based on emission factors for fuel oil combustion in Section 1.3.

[d] S=sulfur content.

[e] Not available.

[f] Based on emission factors for fuel oil combustion in Section 1.3. Evaporative losses only. Hydrocarbon emissions from combustion are considered negligible. Evaporative hydrocarbon losses for units that are part of a pipeline system are negligible.

[g] Negligible.

[h] Little nitrogen oxide is formed because of the relatively low combustion temperatures.

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2. Frost Protection in Citrus. Agricultural Extension Service, University of California, Ventura. November 1967.
3. Personal communication with Mr. Wesley Snowden. Valentine, Fisher, and Tomlinson, Consulting Engineers, Seattle, Washington. May 1971.
4. Communication with the Smith Energy Company, Los Angeles, Calif. January 1968.
5. Communication with Agricultural Extension Service, University of California, Ventura, Calif. October 1969.
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6.10 PHOSPHATE FERTILIZERS

Nearly all phosphatic fertilizers are made from naturally occurring, phosphorus-containing minerals such as phosphate rock. Because the phosphorus content of these minerals is not in a form that is readily available to growing plants, the minerals must be treated to convert the phosphorus to a plant-available form. This conversion can be done either by the process of acidulation or by a thermal process. The intermediate steps of the mining of phosphate rock and the manufacture of phosphoric acid are not included in this section as they are discussed in other sections of this publication: it should be kept in mind, however, that large integrated plants may have all of these operations taking place at one location.

In this section phosphate fertilizers have been divided into three categories: (1) normal superphosphate, (2) triple superphosphate, and (3) ammonium phosphate. Emission factors for the various processes involved are shown in Table 6.10-1.

Table 6.10-1. EMISSION FACTORS FOR THE PRODUCTION OF PHOSPHATE FERTILIZERS
EMISSION FACTOR RATING: C

Type of product	Particulates[a]		Fluorides[b]	
	lb/ton	kg/MT	lb/ton	kg/MT
Normal superphosphate[c]				
Grinding, drying	9	4.5	–	–
Main stack	–	–	0.15	0.075
Triple superphosphate[c]				
Run-of-pile (ROP)	–	–	0.03	0.015
Granular	–	–	0.10	0.05
Diammonium phosphate[d]				
Dryer, cooler	80	40	e	e
Ammoniator-granulator	2	1	0.04	0.02

[a] Control efficiencies of 99 percent can be obtained with fabric filters.

[b] Total fluorides, including particulate fluorides. Factors all represent outlet emissions following control devices, and should be used as typical only in the absence of specific plant information.

[c] References 1 through 3.

[d] References 1, 4, and 5 through 8.

[e] Included in ammoniator-granulator total.

6.10.1 Normal Superphosphate

6.10.1.1 General[4,9] – Normal superphosphate (also called single or ordinary superphosphate) is the product resulting from the acidulation of phosphate rock with sulfuric acid. Normal superphosphate contains from 16 to 22 percent phosphoric anhydride (P_2O_5). The physical steps involved in making superphosphate are: (1) mixing rock and acid, (2) allowing the mix to assume a solid form (denning), and (3) storing (curing) the material to allow the acidulation reaction to be completed. After the curing period, the product can be ground and bagged for sale, the cured superphosphate can be sold directly as run-of-pile product, or the material can be granulated for sale as granulated superphosphate.

6.10.1.2 Emissions – The gases released from the acidulation of phosphate rock contain silicon tetrafluoride, carbon dioxide, steam, particulates, and sulfur oxides. The sulfur oxide emissions arise from the reaction of phosphate rock and sulfuric acid.[10]

If a granulated superphosphate is produced, the vent gases from the granulator-ammoniator may contain particulates, ammonia, silicon tetrafluoride, hydrofluoric acid, ammonium chloride, and fertilizer dust. Emissions from the final drying of the granulated product will include gaseous and particulate fluorides, ammonia, and fertilizer dust.

6.10.2 Triple Superphosphate

6.10.2.1 General[4,9]–Triple superphosphate (also called double or concentrated superphosphate) is the product resulting from the reaction between phosphate rock and phosphoric acid. The product generally contains 44 to 52 percent P_2O_5, which is about three times the P_2O_5 usually found in normal superphosphates.

Presently, there are three principal methods of manufacturing triple superphosphate. One of these uses a cone mixer to produce a pulverized product that is particularly suited to the manufacture of ammoniated fertilizers. This product can be sold as run-of-pile (ROP), or it can be granulated. The second method produces in a multi-step process a granulated product that is well suited for direct application as a phosphate fertilizer. The third method combines the features of quick drying and granulation in a single step.

6.10.2.2 Emissions–Most triple superphosphate is the nongranular type. The exit gases from a plant producing the nongranular product will contain considerable quantities of silicon tetrafluoride, some hydrogen fluoride, and a small amount of particulates. Plants of this type also emit fluorides from the curing buildings.

In the cases where ROP triple superphosphate is granulated, one of the greatest problems is the emission of dust and fumes from the dryer and cooler. Emissions from ROP granulation plants include silicon tetrafluoride, hydrogen fluoride, ammonia, particulate matter, and ammonium chloride.

In direct granulation plants, wet scrubbers are usually used to remove the silicon tetrafluoride and hydrogen fluoride generated from the initial contact between the phosphoric acid and the dried rock. Screening stations and bagging stations are a source of fertilizer dust emissions in this type of process.

6.10.3 AMMONIUM PHOSPHATE

6.10.3.1 General–The two general classes of ammonium phosphates are monammonium phosphate and diammonium phosphate. The production of these types of phosphate fertilizers is starting to displace the production of other phosphate fertilizers because the ammonium phosphates have a higher plant food content and a lower shipping cost per unit weight of P_2O_5.

There are various processes and process variations in use for manufacturing ammonium phosphates. In general, phosphoric acid, sulfuric acid, and anhydrous ammonia are allowed to react to produce the desired grade of ammonium phosphate. Potash salts are added, if desired, and the product is granulated, dried, cooled, screened, and stored.

6.10.3.2 Emissions–The major pollutants from ammonium phosphate production are fluoride, particulates, and ammonia. The largest sources of particulate emissions are the cage mills, where oversized products from the screens are ground before being recycled to the ammoniator. Vent gases from the ammoniator tanks are the major source of ammonia. This gas is usually scrubbed with acid, however, to recover the residual ammonia.

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6.11 STARCH MANUFACTURING

6.11.1 Process Description[1]

The basic raw material in the manufacture of starch is dent corn, which contains starch. The starch in the corn is separated from the other components by "wet milling."

The shelled grain is prepared for milling in cleaners that remove both the light chaff and any heavier foreign material. The cleaned corn is then softened by soaking (steeping) it in warm water acidified with sulfur dioxide. The softened corn goes through attrition mills that tear the kernels apart, freeing the germ and loosening the hull. The remaining mixture of starch, gluten, and hulls is finely ground, and the coarser fiber particles are removed by screening. The mixture of starch and gluten is then separated by centrifuges, after which the starch is filtered and washed. At this point it is dried and packaged for market.

6.11.2 Emissions

The manufacture of starch from corn can result in significant dust emissions. The various cleaning, grinding, and screening operations are the major sources of dust emissions. Table 6.11-1 presents emission factors for starch manufacturing.

Table 6.11-1. EMISSION FACTORS FOR STARCH MANUFACTURING[a]
EMISSION FACTOR RATING: D

Type of operation	Particulates	
	lb/ton	kg/MT
Uncontrolled	8	4
Controlled[b]	0.02	0.01

[a] Reference 2.
[b] Based on centrifugal gas scrubber.

References for Section 6.11

1. Starch Manufacturing. In: Kirk-Othmer Encyclopedia of Chemical Technology, Vol. IX. New York, John Wiley and Sons, Inc. 1964.

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6.12 SUGAR CANE PROCESSING

revised by Tom Lahre

6.12.1 General [1-3]

Sugar cane is burned in the field prior to harvesting to remove unwanted foliage as well as to control rodents and insects. Harvesting is done by hand or, where possible, by mechanical means.

After harvesting, the cane goes through a series of processing steps for conversion to the final sugar product. It is first washed to remove dirt and trash; then crushed and shredded to reduce the size of the stalks. The juice is next extracted by one of two methods, milling or diffusion. In milling, the cane is pressed between heavy rollers to squeeze out the juice; in diffusion, the sugar is leached out by water and thin juices. The raw sugar then goes through a series of operations including clarification, evaporation, and crystallization in order to produce the final product. The fibrous residue remaining after sugar extraction is called bagasse.

All mills fire some or all of their bagasse in boilers to provide power necessary in their milling operation. Some, having more bagasse than can be utilized internally, sell the remainder for use in the manufacture of various chemicals such as furfural.

6.12.2 Emissions [2,3]

The largest sources of emissions from sugar cane processing are the openfield burning in the harvesting of the crop and the burning of bagasse as fuel. In the various processes of crushing, evaporation, and crystallization, relatively small quantities of particulates are emitted. Emission factors for sugar cane field burning are shown in Table 2.4-2. Emission factors for bagasse firing in boilers will be included in Chapter 1 in a future supplement.

References for Section 6.12

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References for Section 6.12

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2. Cooper, J. Unpublished data on emissions from the sugar cane industry. Air Pollution Control Agency, Palm Beach County, Florida. July 1969.

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7. METALLURGICAL INDUSTRY

The metallurgical industries can be broadly divided into primary and secondary metal production operations. The term primary metals refers to production of the metal from ore. The secondary metals industry includes the recovery of metal from scrap and salvage and the production of alloys from ingot.

The primary metals industries discussed in Sections 7.1 through 7.7 include the nonferrous operations of primary aluminum production, copper smelters, lead smelters, and zinc smelters. These industries are characterized by the large quantities of sulfur oxides and particulates emitted. The primary metals industry also includes iron and steel mills, ferroalloy production, and metallurgical coke manufacture.

The secondary metallurgical industries discussed in Sections 7.8 through 7.14 are aluminum operations, brass and bronze ingots, gray iron foundries, lead smelting, magnesium smelting, steel foundries, and zinc processing. The major air contaminants from these operations are particulates in the forms of metallic fumes, smoke, and dust.

7.1 PRIMARY ALUMINUM PRODUCTION

7.1.1 Process Description[1]

Revised by William M. Vatavuk

Bauxite, a hydrated oxide of aluminum associated with silicon, titanium, and iron, is the base ore for aluminum production. Most bauxite ore is purified by the Bayer process in which the ore is dried, ground in ball mills, and mixed with sodium hydroxide. Iron oxide, silica, and other impurities are removed by settling, dilution, and filtration. The aluminum hydroxide is precipitated from this diluted, cooled solution and calcined to produce pure alumina, according to the reaction:

$$\underset{\text{Aluminium hydroxide}}{2Al(OH)_3} \longrightarrow \underset{\text{Water}}{3H_2O} + \underset{\text{Alumina}}{Al_2O_3} \tag{1}$$

Aluminum metal is manufactured by the Hall-Heroult process, which involves the electrolytic reduction of alumina dissolved in a molten salt bath of cryolite (a complex of $NaF \cdot AlF_3$) and various salt additives:

$$\underset{\text{Alumina}}{2Al_2O_3} \xrightarrow{\text{Electrolysis}} \underset{\text{Aluminum}}{4Al} + \underset{\text{Oxygen}}{3O_2} \tag{2}$$

The electrolysis is performed in a carbon crucible housed in a steel shell, known as a "pot." The electrolysis employs the carbon crucible as the cathode (negative pole) and a carbon mass as the anode (positive pole). The type of anode configuration used distinguishes the three types of pots: prebaked (PB), horizontal-stud Soderberg (HSS), and vertical-stud Soderberg (VSS).

The major portion of aluminum produced in the United States (61.9 percent of 1970 production) is processed in prebaked cells. In this type of pot, the anode consists of blocks that are formed from a carbon paste and baked in an oven prior to their use in the cell. These blocks–typically 14 to 24 per cell–are attached to metal rods and serve as replaceable anodes. As the reduction proceeds, the carbon in these blocks is gradually consumed (at a rate of about 1 inch per day) by reaction with the oxygen by-product (see Table 7.1-1).

Table 7.1-1. RAW MATERIAL AND ENERGY REQUIREMENTS FOR ALUMINUM PRODUCTION

Parameter	Representative value
Cell operating temperature	~1740°F (~950°C)
Current through pot line	60,000 to 125,000 amp
Voltage drop per cell	4.3 to 5.2
Current efficiency	85 to 90%
Energy required	6.0 to 8.5 kwh/lb aluminum (13.2 to 18.7 kwh/kg aluminum)
Weight alumina consumed	1.89 to 1.92 lb AL_2O_3/lb aluminum (1.89 to 1.92 kg AL_2O_3/kg aluminum)
Weight electrolyte fluoride consumed	0.03 to 0.10 lb fluoride/lb aluminum (0.03 to 0.10 kg fluoride/kg aluminum)
Weight carbon electrode consumed	0.45 to 0.55 lb electrode/lb aluminum (0.45 to 0.55 kg electrode/kg aluminum)

The second most commonly used furnace (25.5 percent of 1970 production) is the horizontal-stud Soderberg. This type of cell uses a "continuous" carbon anode; that is, a mixture of pitch and carbon aggregate called "paste" is added at the top of the superstructure periodically, and the entire anode assembly is moved downward as the carbon burns away. The cell anode is contained by aluminum sheeting and perforated steel channels, through which electrode connections, called studs, are inserted into the anode paste. As the baking anode is lowered, the lower row of studs and the bottom channel are removed, and the flexible electrical connectors are moved to a higher row. One disadvantage of baking the paste in place is that heavy organic materials (tars) are added to the cell effluent stream. The heavy tars often cause plugging of the ducts, fans, and control equipment, an effect that seriously limits the choice of air cleaning equipment.

The vertical-stud Soderberg is similar to the horizontal-stud furnace, with the exception that the studs are mounted vertically in the cell. The studs must be raised and replaced periodically, but that is a relatively simple process. Representative raw material and energy requirements for aluminum reduction cells are presented in Table 7.1-1. A schematic representation of the reduction process is shown in Figure 7.1-1.

7.1.2 Emissions and Controls[1,2,3]

Emissions from aluminum reduction processes consist primarily of gaseous hydrogen fluoride and particulate fluorides, alumina, hydrocarbons or organics, sulfur dioxide from the reduction cells and the anode baking furnaces. Large amounts of particulates are also generated during the calcining of aluminum hydroxide, but the economic value of this dust is such that extensive controls have been employed to reduce emissions to relatively small quantities. Finally, small amounts of particulates are emitted from the bauxite grinding and materials handling processes.

The source of fluoride emissions from reduction cells is the fluoride electrolyte, which contains cryolite, aluminum fluoride (AlF_3), and fluorspar (CaF_2). For normal operation, the weight or "bath" ratio of sodium fluoride (NaF) to AlF_3 is maintained between 1.36 and 1.43 by the addition of Na_2CO_3, NaF, and AlF_3. Experience has shown that increasing this ratio has the effect of decreasing total fluoride effluents. Cell fluoride emissions are also decreased by lowering the operating temperature and increasing the alumina content in the bath. Specifically, the ratio of gaseous (mainly hydrogen fluoride) to particulate fluorides varies from 1.2 to 1.7 with PB and HSS cells, but attains a value of approximately 3.0 with VSS cells.

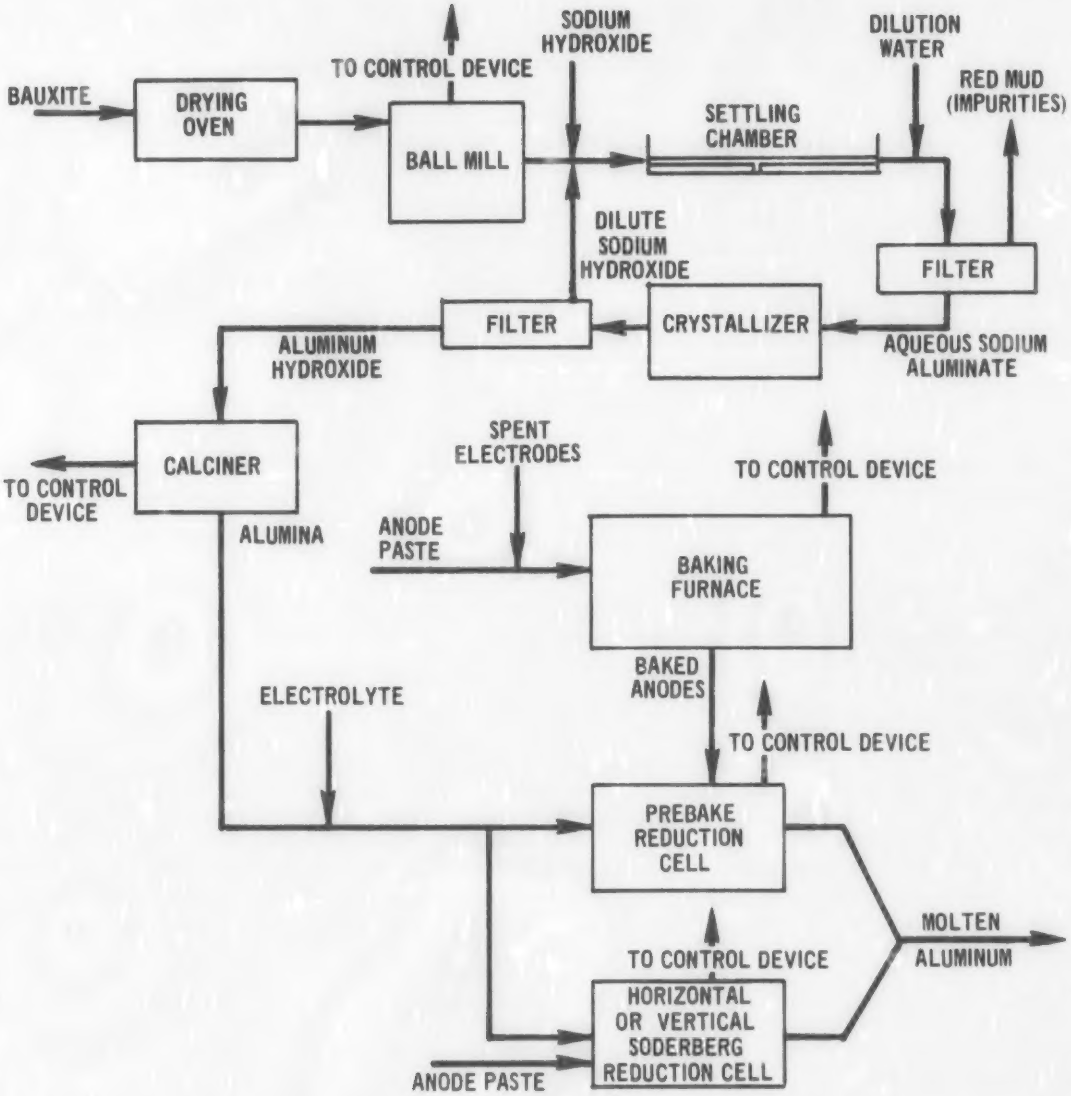
BAUXITE
DRYING OVEN
TO CONTROL DEVICE
BALL MILL
SODIUM HYDROXIDE
SETTLING CHAMBER
DILUTION WATER
RED MUD (IMPURITIES)
DILUTE SODIUM HYDROXIDE
FILTER
FILTER
CRYSTALLIZER
AQUEOUS SODIUM ALUMINATE
ALUMINUM HYDROXIDE
CALCINER
TO CONTROL DEVICE
ALUMINA
SPENT ELECTRODES
ANODE PASTE
TO CONTROL DEVICE
BAKING FURNACE
BAKED ANODES
TO CONTROL DEVICE
ELECTROLYTE
PREBAKE REDUCTION CELL
TO CONTROL DEVICE
MOLTEN ALUMINUM
HORIZONTAL OR VERTICAL SODERBERG REDUCTION CELL
ANODE PASTE

Figure 7.1-1. Schematic diagram of primary aluminum production process.

Table 7.1-2. REPRESENTATIVE PARTICLE SIZE DISTRIBUTIONS OF UNCONTROLLED EFFLUENTS FROM PREBAKED AND HORIZONTAL-STUD SODERBERG CELLS[1]

Size range, μm	Particles within size range, wt%	
	Prebaked	Horizontal-stud Soderberg
<1	35	44
1 to 5	25	26
5 to 10	8	8
10 to 20	5	6
20 to 44	5	4
>44	22	12

Particulate emissions from reduction cells consist of alumina and carbon from anode dusting, cryolite, aluminum fluoride, calcium fluoride, chiolite ($Na_5Al_3F_{14}$), and ferric oxide. Representative size distributions for PB and HSS particulate effluents are presented in Table 7.1-2. Particulates less than 1 micron in diameter represent the largest percentage (35 to 44 percent by weight) of uncontrolled effluents.

Moderate amounts of hydrocarbons derived from the anode paste are emitted from horizontal- and vertical-Soderberg pots. In vertical cells these compounds are removed by combustion via integral gas burners before the off-gases are released.

Because many different kinds of gases and particulates are emitted from reduction cells, many kinds of control devices have been employed. To abate both gaseous and particulate emissions, one or more types of wet scrubbers – spray tower and chambers, quench towers, floating beds, packed beds, venturis, and self-induced sprays – are used on all three cells and on anode baking furnaces. In addition, particulate control methods, such as electrostatic precipitators (wet and dry), multiple cyclones, and dry scrubbers (fluid-bed and coated-filter types), are employed with baking furnaces on PB and VSS cells. Dry alumina adsorption has been used at several PB and VSS installations in foreign countries. In this technique, both gaseous and particulate fluorides are controlled by passing the pot off-gases through the entering alumina feed, on which the fluorides are absorbed; the technique has an overall control efficiency of 98 percent.

In the aluminum hydroxide calcining, bauxite grinding, and materials handling operations, various dry dust collection devices–such as centrifugal collectors, multiple cyclones, or electrostatic precipitators–and wet scrubbers or both may be used. Controlled and uncontrolled emission factors for fluorides and total particulates are presented in Table 7.1.-3.

Table 7.1-3. EMISSION FACTORS FOR PRIMARY ALUMINUM PRODUCTION PROCESSES[a]
EMISSION FACTOR RATING: A

Type of operation	Total particulates[b]		Gaseous fluorides (HF)		Particulate fluorides (F)	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Bauxite grinding[a,c]						
Uncontrolled	6.0	3.0	Neg	Neg	NA[d]	NA
Spray tower	1.8[e]	0.90	Neg	Neg	NA	NA
Floating-bed scrubber	1.7	0.85	Neg	Neg	NA	NA
Quench tower and spray screen	1.0	0.50	Neg	Neg	NA	NA
Electrostatic precipitator	0.12	0.060	Neg	Neg	NA	NA
Calcining of aluminum hydroxide[a,c]						
Uncontrolled	200.0	100.0	Neg	Neg	NA	NA
Spray tower	60.0	30.0	Neg	Neg	NA	NA
Floating-bed scrubber	56.0	28.0	Neg	Neg	NA	NA
Quench tower and spray screen	34.0	17.0	Neg	Neg	NA	NA
Electrostatic precipitator	4.0	2.0	Neg	Neg	NA	NA
Anode baking furnace[f]						
Uncontrolled	3.0 (1.0 to 5.0)[g]	1.5 (0.5 to 2.5)	0.93	0.47	Neg	Neg
Spray tower	NA	NA	0.0372	0.0186	Neg	Neg
Dry electrostatic precipitator	1.13	0.57	0.93	0.47	Neg	Neg
Self-induced spray	0.06	0.03	0.0372	0.0186	Neg	Neg
Prebaked reduction cell[h]						
Uncontrolled	81.3 (11.9 to 177.0)	40.65 (5.95 to 88.5)	24.7 (13.8 to 34.8)	12.35 (6.9 to 17.4)	20.4 (9.8 to 35.5)	10.2 (4.9 to 17.8)
Multiple cyclone	17.9	8.95	24.7	12.35	4.49	2.25
Fluid-bed dry scrubber system	2.02	1.01	0.247	0.124	0.507	0.253

Table 7.1-3 (continued). EMISSION FACTORS FOR PRIMARY ALUMINUN PRODUCTION PROCESSES[a]
EMISSION FACTOR RATING: A

Type of operation	Total particulates[b]		Gaseous fluorides (HF)		Particulate fluorides (F)	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
scrubber system						
Coated filter dry scrubber	1.62	0.81	1.98 to 5.93	0.99 to 2.97	0.408	0.204
Dry electrostatic precipitator	1.62 to 8.94	0.81 to 4.47	24.7	12.35	0.408 to 2.24	0.204 to 1.12
Spray tower	16.2	8.1	0.494 to 2.72	0.247 to 1.36	4.08	2.04
Floating-bed scrubber	16.2	8.1	0.494	0.247	4.08	2.04
Chamber scrubber	12.2	6.1	2.96	1.48	3.06	1.53
Vertical flow packed bed	12.2	6.1	8.4	4.2	3.06	1.53
Dry alumina adsorption	1.62	0.81	0.494	0.247	0.408	0.204
Horizontal-stud Soderberg cell[i]						
Uncontrolled	98.4 (93.6 to 104.0)	49.2 (46.8 to 52.0)	26.6 (25.2 to 28.8)	13.3 (12.6 to 14.4)	15.6 (14.4 to 16.2)	7.8 (7.2 to 8.1)
Spray tower	19.6 to 36.4	9.8 to 18.2	1.86 to 2.39	0.93 to 1.195	3.12 to 5.77	1.56 to 2.885
Floating-bed scrubber	21.6	10.8	0.532	0.266	0.343	0.1715
Wet electrostatic precipitator	7.10	3.55	26.6	13.3	1.13	0.563
Vertical-stud Soderberg cell[j]						
Uncontrolled	78.4	39.2	30.4 (20.0 to 35.0)	15.2 (10.0 to 17.5)	10.6 (5.6 to 55.3)	5.3 (2.8 to 27.7)
Spray tower	19.6	9.8	0.304	0.152	2.65	1.325
Self-induced spray	NA	NA	0.304	0.152	NA	NA
Venturi scrubber	3.14	1.57	0.304	0.152	0.424	0.212
Wet electrostatic precipitator	0.784 to 7.84	0.392 to 3.92	30.4	15.2	0.106 to 1.06	0.053 to 0.53
Multiple cyclones	3.92 to 4.7	1.96 to 2.35	30.4	15.2	5.30 to 6.36	2.65 to 3.18
Dry alumina adsorption	1.57	0.784	0.608	0.304	0.212	0.106
Materials handling[c]						
Uncontrolled	10.0	5.0	Neg	Neg	NA	NA
Spray tower	3.0	1.5	Neg	Neg	NA	NA

Table 7.1-3 (continued). EMISSION FACTORS FOR PRIMARY ALUMINUM PRODUCTION PROCESSES[a] EMISSION FACTOR RATING: A

Type of operation	Total particulates[b]		Gaseous fluorides (HF)		Particulate fluorides (F)	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Floating-bed scrubber	2.8	1.4	Neg	Neg	NA	NA
Quench tower and spray screen	1.7	0.85	Neg	Neg	NA	NA
Electrostatic precipitator	0.20	0.10	Neg	Neg	NA	NA

[a] Emission factors for bauxite grinding expressed as pounds per ton (kg/MT) of bauxite processed. Factors for calcining of aluminum hydroxide expressed as pounds per ton (kg/MT) of alumina produced. All other factors in terms of tons (MT) of molten aluminum produced.

[b] Includes particulate fluorides.

[c] References 1 and 3.

[d] No information available.

[e] Controlled emission factors are based on average uncontrolled factors and on average observed collection efficiencies.

[f] References 1,2, and 4 through 6.

[g] Numbers in parentheses are ranges of uncontrolled values observed.

[h] References 2 and 4 through 6.

[i] Reference 1.

[j] References 2 and 6.

References for Section 7.1

1. Engineering and Cost Effectiveness Study of Fluoride Emissions Control, Vol. I. TRW Systems and Resources Research Corp., Reston, Va. Prepared for Environmental Protection Agency, Office of Air Programs, Research Triangle Park, N.C., under Contract Number EHSD-71-14. January 1972.

2. Air Pollution Control in the Primary Aluminum Industry, Vol. I. Singmaster and Breyer, New York, N.Y. Prepared for Environmental Protection Agency, Office of Air Programs, Research Triangle Park, N.C., under Contract Number CPA-70-21. March 1972.

3. Particulate Pollutant System Study, Vol. I. Midwest Research Institute, Kansas City, Mo. Prepared for Environmental Protection Agency, Office of Air Programs, Research Triangle Park, N.C. May 1971.

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5. Source Testing Report: Emissions from Primary Aluminum Smelting Plant. York Research Corp., Stamford, Conn. Prepared for Environmental Protection Agency, Office of Air Programs, Research Triangle Park, N.C. Report Number Y-7730-B. June 1972.

6. Source Testing Report: Emissions from the Wet Scrubber System. York Research Corp., Stamford, Conn. Prepared for Environmental Protection Agency, Office of Air Programs, Research Triangle Park, N.C. Report Number Y-7730-F. June 1972.

7.2 METALLURGICAL COKE MANUFACTURING

7.2.1 Process Description[1]

Coking is the process of heating coal in an atmosphere of low oxygen content, i.e., destructive distillation. During this process, organic compounds in the coal break down to yield gases and a residue of relatively nonvolatile nature. Two processes are used for the manufacture of metallurgical coke, the beehive process and the by-product process; the by-product process accounts for more than 98 percent of the coke produced.

Beehive oven:[1] The beehive is a refractory-lined enclosure with a dome-shaped roof. The coal charge is deposited onto the floor of the beehive and leveled to give a uniform depth of material. Openings to the beehive oven are then restricted to control the amount of air reaching the coal. The carbonization process begins in the coal at the top of the pile and works down through it. The volatile matter being distilled escapes to the atmosphere through a hole in the roof. At the completion of the coking time, the coke is "watered out" or quenched.

By-product process:[1] The by-product process is oriented toward the recovery of the gases produced during the coking cycle. The rectangular coking ovens are grouped together in a series, alternately interspersed with heating flues, called a coke battery. Coal is charged to the ovens through ports in the top, which are then sealed. Heat is supplied to the ovens by burning some of the coke gas produced. Coking is largely accomplished at temperatures of 2000° to 2100° F (1100° to 1150° C) for a period of about 16 to 20 hours. At the end of the coking period, the coke is pushed from the oven by a ram and quenched with water.

7.2.2 Emissions[1]

Visible smoke, hydrocarbons, carbon monoxide, and other emissions originate from the following by-product coking operations: (1) charging of the coal into the incandescent ovens, (2) oven leakage during the coking period, (3) pushing the coke out of the ovens, and (4) quenching the hot coke. Virtually no attempts have been made to prevent gaseous emissions from beehive ovens. Gaseous emissions from the by-product ovens are drawn off to a collecting main and are subjected to various operations for separating ammonia, coke-oven gas, tar, phenol, light oil (benzene, toluene, xylene), and pyridine. These unit operations are potential sources of hydrocarbon emissions.

Oven-charging operations and leakage around poorly sealed coke-oven doors and lids are major sources of gaseous emissions from by-product ovens. Sulfur is present in the coke-oven gas in the form of hydrogen sulfide and carbon disulfide. If the gas is not desulfurized, the combustion process will emit sulfur dioxide.

Associated with both coking processes are the material-handling operations of unloading coal, storing coal, grinding and sizing of coal, screening and crushing coke, and storing and loading coke. All of these operations are potential particulate emission sources. In addition, the operations of oven charging, coke pushing and quenching produce particulate emissions. The emission factors for coking operations are summarized in Table 7.2-1.

Table 7.2-1. EMISSION FACTORS FOR METALLURGICAL COKE MANUFACTURE WITHOUT CONTROLS[a]

EMISSION FACTOR RATING: C

Type of operation	Particulates		Sulfur dioxide		Carbon monoxide		Hydrocarbons[b]		Nitrogen oxides (NO_2)		Ammonia	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
By-product coking[c]												
Unloading	0.4	0.2	–	–	–	–	–	–	–	–	–	–
Charging	1.5	0.75	0.02	0.01	0.6	0.3	2.5	1.25	0.03	0.015	0.02	0.01
Coking cycle	0.1	0.05	–	–	0.6	0.3	1.5	0.75	0.01	0.005	0.06	0.03
Discharging	0.6	0.3	–	–	0.07	0.035	0.2	0.1	–	–	0.1	0.05
Quenching	0.9	0.45	–	–	–	–	–	–	–	–	–	–
Underfiring[d]	–	–	4	2	–	–	–	–	–	–	–	–
Beehive ovens[e]	200	100	–	–	1	0.5	8	4	–	–	2	1

[a] Emission factors expressed as units per unit weight of coal charged.

[b] Expressed as methane.

[c] References 2 and 3

[d] Reference 5. The sulfur dioxide factor is based on the following representative conditions: (1) sulfur content of coal charged to oven is 0.8 percent by weight; (2) about 33 percent by weight of total sulfur in the coal charged to oven is transferred to the coke oven gas; (3) about 40 percent of coke-oven gas is burned during the underfiring operation and the remainder is used in other parts of the steel operation where the rest of the sulfur dioxide is discharged—about 6 lb/ton (3 kg/MT) of coal charged; and (4) gas used in underfiring has not been desulfurized.

[e] References 1 and 4.

References for Section 7.2

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3. Fullerton, R.W. Impingement Baffles to Reduce Emissions from Coke Quenching. J. Air Pol. Control Assoc. *17*:807-809. December 1967.

4. Sallee, G. Private Communication on Particulate Pollutant Study. Midwest Research Institute, Kansas City, Mo. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number 22-69-104. June 1970.

5. Varga, J. and H.W. Lownie, Jr. Final Technological Report on: A Systems Analysis Study of the Integrated Iron and Steel Industry. Battelle Memorial Institute, Columbus, Ohio. Prepared for U.S. DHEW, National Air Pollution Control Administration, Durham, N.C., under Contract Number PH 22-68-65. May 1969.

7.3 COPPER SMELTERS

7.3.1 Process Description[1,2]

Copper is produced primarily from low-grade sulfide ores, which are concentrated by gravity and flotation methods. Copper is recovered from the concentrate by four steps: roasting, smelting, converting, and refining. Copper sulfide concentrates are normally roasted in either multiple-hearth or fluidized-bed roasters to remove the sulfur and then calcined in preparation for smelting in a reverberatory furnace. For about half the smelters the roasting step is eliminated. Smelting removes other impurities as a slag with the aid of fluxes. The matter that results from smelting is blown with air to remove the sulfur as sulfur dioxide, and the end product is a crude metallic copper. A refining process further purifies the metal by insertion of green logs or natural gas. This is often followed by electrolytic refining.

7.3.2 Emissions and Controls[2]

The high temperatures attained in roasting, smelting, and converting cause volatilization of a number of the trace elements present in copper ores and concentrates. The raw waste gases from these processes contain not only these fumes but also dust and sulfur oxide. Carbon monoxide and nitrogen oxides may also be emitted, but no quantitative data have been reported in the literature.

The value of the volatilized elements dictates efficient collection of fumes and dusts. A combination of cyclones and electrostatic precipitators seems to be most often used. Table 7.3-1 summarizes the uncontrolled emissions of particulates and sulfur oxides from copper smelters.

Table 7.3-1. EMISSION FACTORS FOR PRIMARY COPPER SMELTERS WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: C

Type of operation	Particulates[b,c]		Sulfur oxides[d]	
	lb/ton	kg/MT	lb/ton	kg/MT
Roasting	45	22.5	60	30
Smelting (reverberatory furnace)	20	10	320	160
Converting	60	30	870	435
Refining	10	5	–	–
Total uncontrolled	135	67.5	1250	625

[a] Approximately 4 unit weights of concentrate are required to produce 1 unit weight of copper metal. Emission factors expressed as units per unit weight of concentrated ore produced.

[b] References 2 through 4.

[c] Electrostatic precipitators have been reported to reduce emissions by 99.7 percent.

[d] Sulfur oxides can be reduced by about 90 percent by using a combination of sulfuric acid plants and lime slurry scrubbing.

References for Section 7.3

1. Duprey, R.L. Compilation of Air Pollutant Emission Factors. U. S. DHEW PHS, National Center for Air Pollution Control. Durham, N. C. PHS Publication No. 999-AP-42. 1968. p. 24.

2. Stern, A. (ed.). Sources of Air Pollution and Their Control. In: Air Pollution, Vol. III, 2nd Ed. New York, Academic Press. 1968. p. 173-179.

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4. Systems Study for Control of Emissions in the Primary Nonferrous Smelting Industry. 3 Volumes. San Francisco, California, Arthur G. McKee and Company. June 1969.

7.4 FERROALLOY PRODUCTION

7.4.1 Process Description[1,2]

Ferroalloy is the generic term for alloys consisting of iron and one or more other metals. Ferroalloys are used in steel production as alloying elements and deoxidants. There are three basic types of ferroalloys: (1) silicon-based alloys, including ferrosilicon and calciumsilicon; (2) manganese-based alloys, including ferromanganese and silicomanganese; and (3) chromium-based alloys, including ferrochromium and ferrosilicochrome.

The four major procedures used to produce ferroalloy and high-purity metallic additives for steelmaking are: (1) blast furnace, (2) electrolytic deposition, (3) alumina silico-thermic process, and (4) electric smelting furnace. Because over 75 percent of the ferroalloys are produced in electric smelting furnaces, this section deals only with that type of furnace.

The oldest, simplest, and most widely used electric furnaces are the submerged-arc open type, although semi-covered furnaces are also used. The alloys are made in the electric furnaces by reduction of suitable oxides. For example, in making ferrochromium the charge may consist of chrome ore, limestone, quartz (silica), coal and wood chips, along with scrap iron.

7.4.2 Emissions[3]

The production of ferroalloys has many dust- or fume-producing steps. The dust resulting from raw material handling, mix delivery, and crushing and sizing of the solidified product can be handled by conventional techniques and is ordinarily not a pollution problem. By far the major pollution problem arises from the ferroalloy furnaces themselves. The conventional submerged-arc furnace utilizes carbon reduction of metallic oxides and continuously produces large quantities of carbon monoxide. This escaping gas carries large quantities of particulates of submicron size, making control difficult.

In an open furnace, essentially all of the carbon monoxide burns with induced air at the top of the charge, and CO emissions are small. Particulate emissions from the open furnace, however, can be quite large. In the semi-closed furnace, most or all of the CO is withdrawn from the furnace and burns with dilution air introduced into the system. The unburned CO goes through particulate control devices and can be used as boiler fuel or can be flared directly. Particulate emission factors for electric smelting furnaces are presented in Table 7.4-1. No carbon monoxide emission data have been reported in the literature.

Table 7.4-1. EMISSION FACTORS FOR FERROALLOY PRODUCTION IN ELECTRIC SMELTING FURNACES[a]
EMISSION FACTOR RATING: C

Type of furance and product	Particulates	
	lb/ton	kg/MT
Open furnace		
50% FeSi[b]	200	100
75% FeSi[c]	315	157.5
90% FeSi[b]	565	282.5
Silicon metal[d]	625	312.5
Silicomanganese[e]	195	97.5
Semi-covered furnace		
Ferromanganese[e]	45	22.5

[a] Emission factors expressed as units per unit weight of specified product produced.

[b] Reference 4.

[c] References 5 and 6.

[d] References 4 and 7.

[e] Reference 6.

References for Section 7.4

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2. Ferroalloys: Steel's All-purpose Additives. The Magazine of Metals Producing. February 1967.

3. Person, R. A. Control of Emissions from Ferroalloy Furnace Processing. Niagara Falls, New York. 1969.

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5. Ferrari, R. Experiences in Developing an Effective Pollution Control System for a Submerged-Arc Ferroalloy Furnace Operation. J. Metals. p. 95-104, April 1968.

6. Fredriksen and Nestaas. Pollution Problems by Electric Furnace Ferroalloy Production. United Nations Economic Commission for Europe. September 1968.

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7.5 IRON AND STEEL MILLS

Revised by William M. Vatavuk
and L.K. Felleisen

7.5.1 General[1]

Iron and steel manufacturing processes may be grouped into five distinct sequential operations: (1) coke production; (2) pig iron manufacture in blast furnaces; (3) steel-making processes using basic oxygen, electric arc, and open hearth furnaces; (4) rolling mill operations; and (5) finishing operations (see Figure 7.5-1). The first three of these operations encompass nearly all of the air pollution sources. Coke production is discussed in detail elsewhere in this publication.

7.5.1.1 Pig Iron Manufacture[2,3] –Pig iron is produced in blast furnaces, which are large refractory-lined chambers into which iron ore, coke, and limestone are charged and allowed to react with large amounts of hot air to produce molten iron. Slag and blast furnace gases are by-products of this operation. The production of 1 unit weight of pig iron requires an average charge of 1.55 unit weights of iron-bearing charge, 0.55 unit weight of coke, 0.20 unit weight of limestone, and 2.3 unit weight of air. Blast furnace by-products consist of 0.2 unit weight of slag, 0.02 unit weight of flue dust, and 2.5 unit weights of gas per unit of pig iron produced. Most of the coke used in the process is produced in by-product coke ovens. The flue dust and other iron ore fines from the process are converted into useful blast furnace charge via sintering operations.

Blast furnace combustion gas and the gases that escape from bleeder openings constitute the major sources of particulate emissions. The dust in the gas consists of 35 to 50 percent iron, 4 to 14 percent carbon, 8 to 13 percent silicon dioxide, and small amounts of aluminum oxide, manganese oxide, calcium oxide, and other materials. Because of its high carbon monoxide content, this gas has a low heating value (about 100 Btu/ft) and is utilized as a fuel within the steel plant. Before it can be efficiently oxidized, however, the gas must be cleaned of particulates. Initially, the gases pass through a settling chamber or dry cyclone, where about 60 percent of the dust is removed. Next, the gases undergo a one- or two-stage cleaning operation. The primary cleaner is normally a wet scrubber, which removes about 90 percent of the remaining particulates. The secondary cleaner is a high-energy wet scrubber (usually a venturi) or an electrostatic precipitator, either of which can remove up to 90 percent of the particulates that have passed through the primary cleaner. Taken together, these control devices provide an overall dust removal efficiency of approximately 96 percent.

All of the carbon monoxide generated in the gas is normally used for fuel. Conditions such as "slips," however, can cause instantaneous emissions of carbon monoxide. Improvements in techniques for handling blast furnace burden have greatly reduced the occurrence of slips. In Table 7.5-1 particulate and carbon monoxide emission factors are presented for blast furnaces.

7.5.1.2 Steel-Making Processes -

7.5.1.2.1 Open Hearth Furnaces[2,3] –In the open hearth process, a mixture of scrap iron, steel, and pig iron is melted in a shallow rectangular basin, or "hearth," for which various liquid gaseous fuels provide the heat. Impurities are removed in a slag.

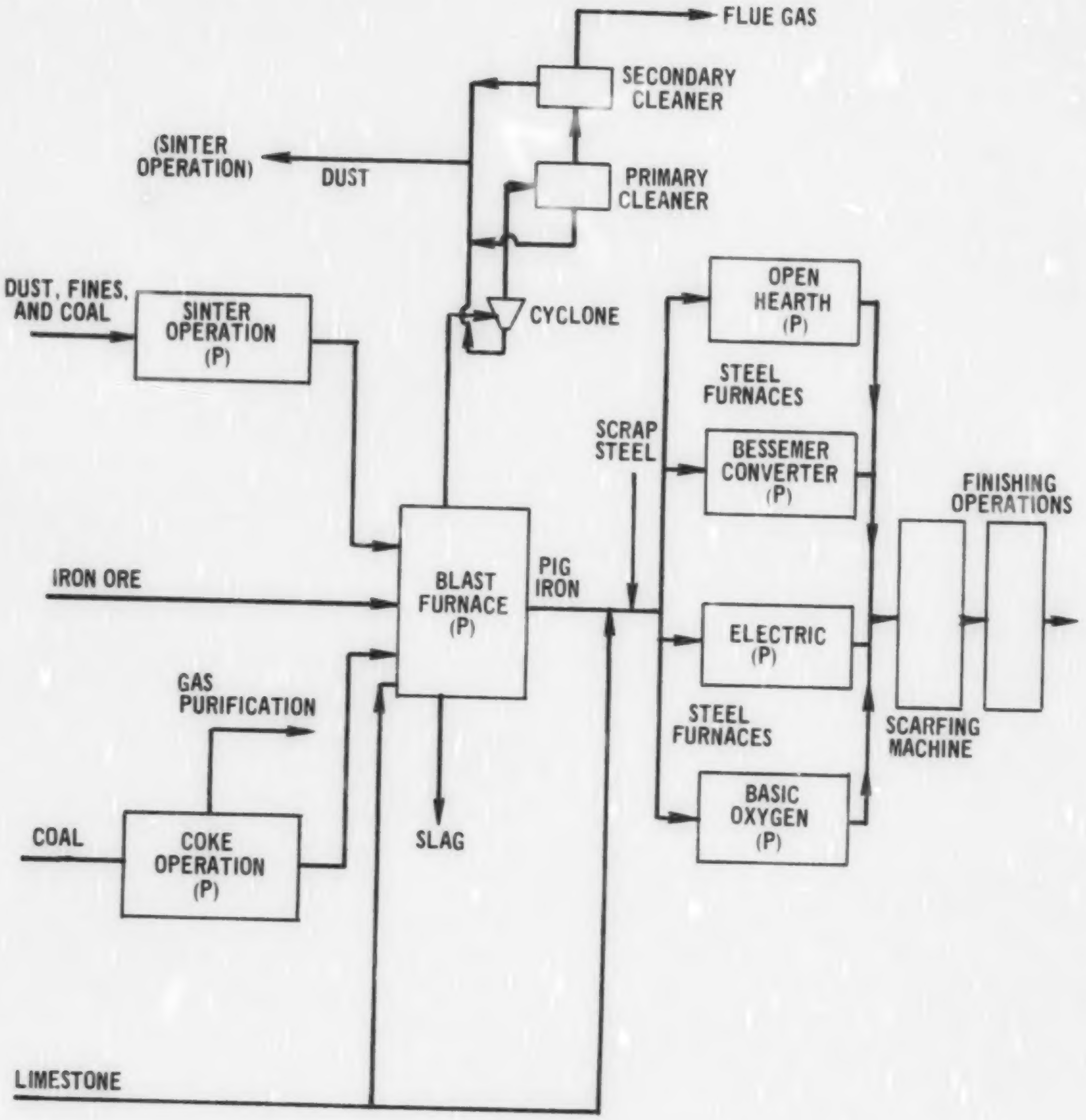
FLUE GAS
SECONDARY CLEANER
(SINTER OPERATION)
DUST
PRIMARY CLEANER
DUST, FINES, AND COAL
SINTER OPERATION (P)
CYCLONE
OPEN HEARTH (P)
STEEL FURNACES
SCRAP STEEL
BESSEMER CONVERTER (P)
FINISHING OPERATIONS
IRON ORE
BLAST FURNACE (P)
PIG IRON
ELECTRIC (P)
GAS PURIFICATION
STEEL FURNACES
SCARFING MACHINE
COAL
COKE OPERATION (P)
SLAG
BASIC OXYGEN (P)
LIMESTONE

Figure 7.5-1. Basic flow diagram of iron and steel processes. "P" denotes a major source of particulate emissions.

Emissions from open hearths consist of particulates and small amounts of fluorides when fluoride-bearing ore, fluorspar, is used in the charge. The particulates are composed primarily of iron oxides, with a large portion (45 to 50 percent) in the 0 to 5 micrometer size range. The quantity of dust in the off-gas increases considerably when oxygen lancing is used (see Table 7.5-1).

The devices most commonly used to control the iron oxide and fluoride particulates are electrostatic precipitators and high-energy venturi scrubbers, both of which effectively remove about 98 percent of the particulates. The scrubbers also remove nearly 99 percent of the gaseous fluorides and 95 percent of the particulate fluorides.

7.5.1.2.2 Basic Oxygen Furnaces[2,3] – The basic oxygen process, also called the Linz-Donawitz (LD) process, is employed to produce steel from a furnace charge composed of approximately 70 percent molten blast-furnace metal and 30 percent scrap metal by use of a stream of commercially pure oxygen to oxidize the impurities, principally carbon and silicon.

The reaction that converts the molten iron into steel generates a considerable amount of particulate matter, largely in the form of iron oxide, although small amounts of fluorides may be present. Probably as the result of the tremendous agitation of the molten bath by the oxygen lancing, the dust loadings vary from 5 to 8 grams per standard cubic foot (11 to 18 grams/standard cubic meter) and high percentages of the particles are in the 0 to 5 micrometer size range.

In addition, tremendous amounts of carbon monoxide (140 lb/ton of steel and more) are generated by the reaction. Combustion in the hood, direct flaring, or some other means of ignition is used in the stack to reduce the actual carbon monoxide emissions to less than 3 lb/ton (1.5 kg/MT).

The particulate control devices used are venturi scrubbers and electrostatic precipitators, both of which have overall efficiencies of 99 percent. Furthermore, the scrubbers are 99 percent efficient in removing gaseous fluorides (see Table 7.5-1).

7.5.1.2.3 Electric Arc Furnaces[2,3] Electric furnaces are used primarily to produce special alloy steels or to melt large amounts of scrap for reuse. Heat is furnished by direct-arc electrodes extending through the roof of the furnace. In recent years, oxygen has been used to increase the rate of uniformity of scrap-melt-down and to decrease power consumption.

The particulates, primarily oxides of iron, manganese, aluminum, and silicon, that evolve when steel is being processed in an electric furnace result from the exposure of molten steel to extremely high temperatures. The quantity of these emissions is a function of the cleanliness and composition of the scrap metal charge, the refining procedure used (with or without oxygen lancing), and the refining time. As with open hearths, many of the particulates (40 to 75 percent) are in the 0 to 5 micrometer range. Additionally, moderate amounts of carbon monoxide (15 to 20 lb/ton) are emitted.

Particulate control devices most widely used with electric furnaces are venturi scrubbers, which have a collection efficiency of approximately 98 percent, and bag filters, which have collection efficiencies of 99 percent or higher.

7.5.1.3 Scarfing[3] – Scarfing is a method of surface preparation of semi-finished steel. A scarfing machine removes surface defects from the steel billets and slabs, before they are shaped or rolled, by applying jets of oxygen to the surface of the steel, which is at orange heat, thus removing a thin upper layer of the metal by rapid oxidation.

Emissions from scarfing operations consist of iron oxide fumes. The rate at which particulates are emitted is dependent on the condition of the billets or slabs and the amount of metal removal required (Table 7.5-1). Emission control techniques for the removal of fine particles vary among steel producers, but one of the most commonly used devices is the electrostatic precipitator, which is approximately 94 percent efficient.

Table 7.5-1. EMISSION FACTORS FOR IRON AND STEEL MILLS[a,b]
EMISSION FACTOR RATINGS: A (PARTICULATES AND CARBON MONOXIDE)
C (FLUORIDES)

Type of operation	Total particulates		Carbon monoxide		Fluorides[c,d]			
					Gaseous (HF)		Particulates (CaF_2)	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Pig iron production								
Blast furnaces[e]								
Ore charge, uncontrolled	110	55	1750 (1400 to 2100)	875 (700 to 1050)	–	–	–	–
Agglomerates charge, uncontrolled	40	20	–	–	–	–	–	–
Total, uncontrolled	150 (130 to 200)	75 (65 to 100)	1750 (1400 to 2100)	875 (700 to 1050)	–	–	–	–
Settling chamber or dry cyclone	60	30	–	–	–	–	–	–
Plus wet scrubber	15	7.5	–	–	–	–	–	–
Plus venturi or electrostatic precipitator	1.5	0.75	–	–	–	–	–	–
Sintering[f]								
Windbox, uncontrolled[g]	20	10	–	–	–	–	–	–
Dry cyclone	2.0	1.0	–	–	–	–	–	–
Dry cyclone plus electrostatic precipitator	1.0	0.5	–	–	–	–	–	–
Dry cyclone plus wet scrubber	0.04	0.02	–	–	–	–	–	–
Discharge, uncontrolled	22	11	44	22	–	–	–	–
Dry cyclone	2.2	1.1	44	22	–	–	–	–
Dry cyclone plus electrostatic precipitator	0.11	0.055	44	22	–	–	–	–
Steel production								
Open hearth[h]								
No oxygen lance, uncontrolled	8.3 (5.8 to 12.0)	4.15 (2.9 to 6.0)	–	–	0.100	0.05	0.030	0.015
Venturi scrubber	0.17	0.085	–	–	0.011	0.0055	0.0015	0.0008
Electrostatic precipitator	0.17	0.085	–	–	0.100	0.050	0.0006	0.0003
Oxygen lance, uncontrolled	17.4 (9.3 to 22.0)	8.7 (4.65 to 11.0)	–	–	0.100	0.050	0.030	0.015

Table 7.5-1 (continued). EMISSION FACTORS FOR IRON AND STEEL MILLS[a,b]
EMISSION FACTOR RATINGS: A (PARTICULATES AND CARBON MONOXIDE)
C (FLUORIDES)

Type of operation	Total particulates		Carbon monoxide		Fluorides[c,d]			
					Gaseous (HF)		Particulates (CaF_2)	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Venturi scrubber	0.17	0.085	–	–	0.011	0.0055	0.0015	0.0008
Electrostatic precipitator	0.35	0.175	–	–	0.100	0.050	0.0006	0.0003
Basic oxygen, uncontrolled[j]	51 (32 to 86)	25.5 (16 to 43)	139 (104 to 237)	69.5 (52.0 to 118.5)	Neg	Neg	0.200	0.100
Venturi scrubber	0.51	0.255	–	–	–	–	0.002	0.001
Electrostatic precipitator	0.51	0.255	–	–	–	–	0.002	0.001
Spray chamber	15.3	7.65	–	–	–	–	0.060	0.030
Electric arc[k]								
No oxygen lance[l], uncontrolled	9.2 (7.0 to 10.6)	4.6 (3.5 to 5.3)	18	9	0.012	0.006	0.238	0.119
Venturi scrubber	0.18	0.09	18	9	0.0018	0.0009	0.011	0.0055
Electrostatic precipitator	0.28 to 0.74	0.14 to 0.37	18	9	0.012	0.006	0.011	0.0055
Baghouse	0.09	0.045	18	9	0.012	0.006	0.0024	0.0012
Oxygen lance[m], uncontrolled	11	5.5	18	9	0.012	0.006	0.238	0.119
Venturi scrubber	0.22	0.11	18	9	0.0018	0.0009	0.011	0.0055
Electrostatic precipitator	0.33 to 0.88	0.165 to 0.44	18	9	0.012	0.006	0.011	0.0055
Baghouse	0.11	0.055	18	9	0.012	0.006	0.0024	0.0012
Scarfing[n], uncontrolled	≤1	≤0.5	–	–	–	–	–	–
Electrostatic precipitator	≤0.06	≤0.03	–	–	–	–	–	–
Venturi scrubber	≤0.02	≤0.01	–	–	–	–	–	–

[a] Emission factors expressed as units per unit weight of metal produced.

[b] Numbers in parentheses after uncontrolled values are ranges. Controlled factors are calculated using average uncontrolled factors and observed equipment efficiencies.

[c] Reference 4.

[d] Value included in "Total Particulates" figure.

[e] References 2, 3, and 5.

[f] These factors should be used to estimate particulate and carbon monoxide emissions from the entire blast furnace operation. The total particulate factors for ore charging and agglomerates charging apply only to those operations.

[g] Reference 3.

[h] Approximately 0.3 pounds of sulfur dioxide per ton (0.15 kg/MT) of sinter is produced at windbox.

[i] References, 2, 3, 5, and 6.

[j] References 2 through 10.

[k] Values are for carbon type electric arc furnaces. For alloy type furnaces, multiply given values by 2.80.

[l] References 2 through 5.

[m] References 3 and 4.

[n] Factors are based on operating experience and engineering judgment.

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7.6 LEAD SMELTING

Revised by William M. Vatavuk

7.6.1 Process Description [1-3]

Lead is usually found in nature as a sulfide ore containing small amounts of copper, iron, zinc, and other trace elements. It is normally concentrated at the mine from an ore of 3 to 8 percent lead to an ore concentrate of 55 to 70 percent lead, containing from 13 to 19 percent free and uncombined sulfur by weight.

Normal practice for the production of lead metal from this concentrate involves the following operations (see Figure 7.6-1):

1. Sintering, in which the concentrate lead and sulfur are oxidized to produce lead oxide and sulfur dioxide. (Simultaneously, the charge material, comprised of concentrates, recycle sinter, sand, and other inert materials, is agglomerated to form a dense, permeable material called sinter.)
2. Reducing the lead oxide contained in the sinter to produce molten lead bullion.
3. Refining the lead bullion to eliminate any impurities.

Sinter is produced by means of a sinter machine, a continuous steel-pallet conveyor belt moved by gears and sprockets. Each pallet consists of perforated or slotted grates, beneath which are situated windboxes connected to fans that provide a draft on the moving sinter charge. Depending on the direction of this draft, the sinter machine is either of the updraft or downdraft type. Except for the draft direction, however, all machines are similar in design, construction, and operation.

The sintering reaction is autogenous and occurs at a temperature of approximately 1000°C:

$$2\,PbS + 3\,O_2 \rightarrow 2\,PbO + 2\,SO_2 \qquad (1)$$

Operating experience has shown that system operation and product quality are optimum when the sulfur content of the sinter charge is between 5 and 7 percent by weight. To maintain this desired sulfur content, sulfide-free fluxes such as silica and limestone, plus large amounts of recycled sinter and smelter residues are added to the mix. The quality of the product sinter is usually determined by its hardness (Ritter Index), which is inversely proportional to the sulfur content. Hard quality sinter (low sulfur content) is preferred because it resists crushing during discharge from the sinter machine. Conversely, undersized sinter will usually result from insufficient desulfurization and is recycled for further processing.

Of the two kinds of sintering machines used, the updraft design is superior for many reasons. First, the sinter bed height is more permeable (and, hence, can be greater) with an updraft machine, thereby permitting a higher production rate than that of a downdraft machine of similar dimensions. Secondly, the small amounts of elemental lead that form during sintering will solidify at their point of formation with updraft machines; whereas, in downdraft operation, the metal tends to flow downward and collect on the grates or at the bottom of the sinter charge, thus causing increased pressure drop and attendant reduced blower capacity. In addition, the updraft system exhibits the capability of producing sinter of higher lead content and requires less maintenance than the downdraft machine. Finally, and most important from an air pollution control standpoint, updraft sintering can produce a single strong SO_2 effluent stream from the operation, by use of weak gas recirculation. This, in turn, permits the more efficient and economical use of such control methods as sulfuric acid recovery plants.

Lead reduction is carried out in a blast furnace, basically a water-jacketed shaft furnace supported by a refractory base. Tuyeres, through which combustion air is admitted under pressure, are located near the bottom and are evenly spaced on either side of the furnace.

The furnace is charged with a mixture of sinter (80 to 90 percent of charge), metallurgical coke (8 to 14 percent of the charge), and other materials, such as limestone, silica, litharge, slag-forming constituents, and various recycled and clean-up materials. In the furnace the sinter is reduced to lead bullion; most of the impurities are

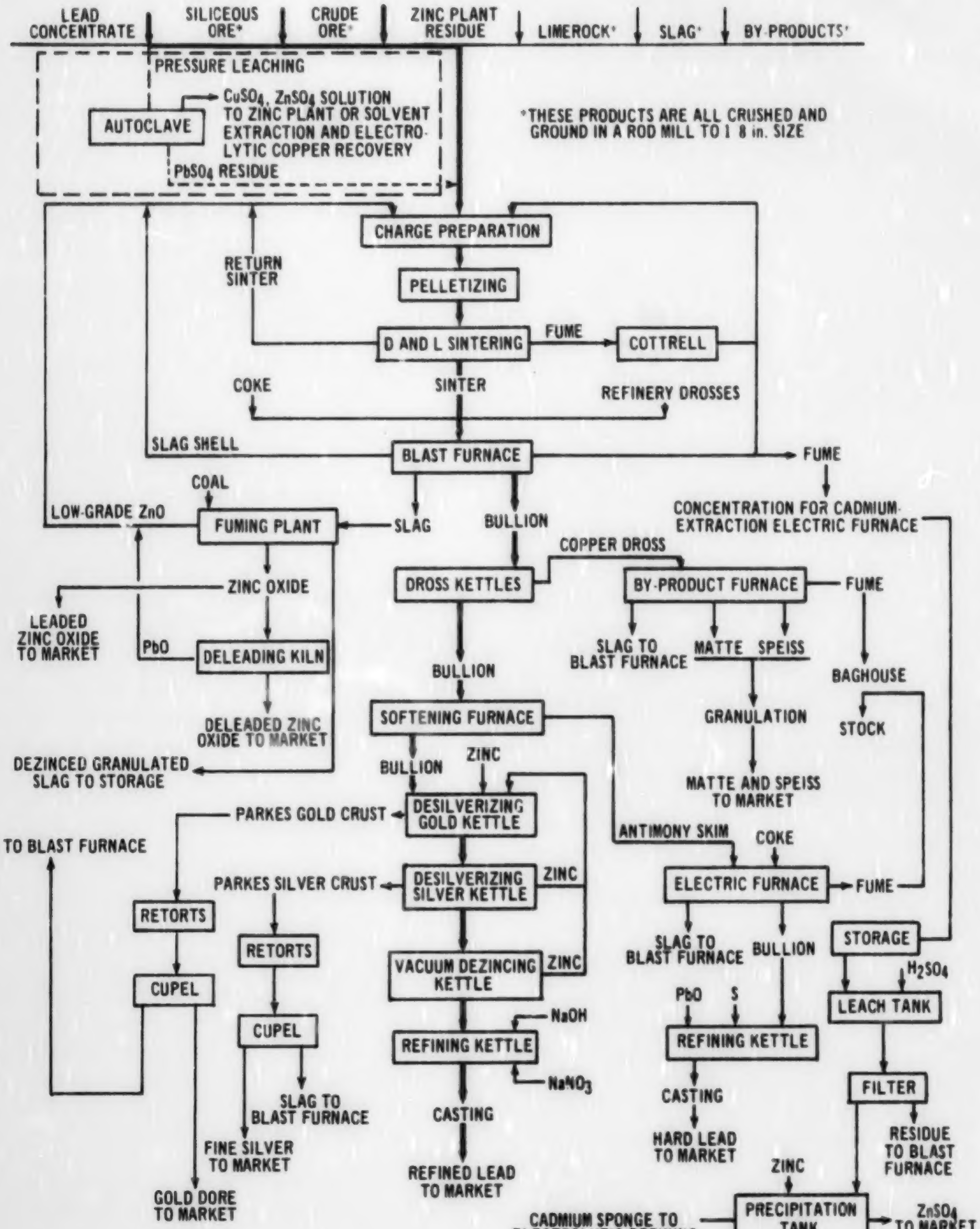
LEAD CONCENTRATE
SILICEOUS ORE*
CRUDE ORE*
ZINC PLANT RESIDUE
LIMEROCK*
SLAG*
BY-PRODUCTS*
PRESSURE LEACHING
AUTOCLAVE
$CuSO_4$, $ZnSO_4$ SOLUTION TO ZINC PLANT OR SOLVENT EXTRACTION AND ELECTROLYTIC COPPER RECOVERY
$PbSO_4$ RESIDUE
*THESE PRODUCTS ARE ALL CRUSHED AND GROUND IN A ROD MILL TO 1/8 in. SIZE
CHARGE PREPARATION
RETURN SINTER
PELLETIZING
D AND L SINTERING
FUME
COTTRELL
COKE
SINTER
REFINERY DROSSES
SLAG SHELL
BLAST FURNACE
FUME
COAL
LOW-GRADE ZnO
FUMING PLANT
SLAG
BULLION
CONCENTRATION FOR CADMIUM EXTRACTION ELECTRIC FURNACE
COPPER DROSS
DROSS KETTLES
BY-PRODUCT FURNACE
FUME
ZINC OXIDE
LEADED ZINC OXIDE TO MARKET
PbO
DELEADING KILN
SLAG TO BLAST FURNACE
MATTE
SPEISS
BULLION
BAGHOUSE
SOFTENING FURNACE
GRANULATION
STOCK
DELEADED ZINC OXIDE TO MARKET
BULLION
ZINC
DEZINCED GRANULATED SLAG TO STORAGE
MATTE AND SPEISS TO MARKET
PARKES GOLD CRUST
DESILVERIZING GOLD KETTLE
ANTIMONY SKIM
COKE
AG TO BLAST FURNACE
PARKES SILVER CRUST
DESILVERIZING SILVER KETTLE
ZINC
ELECTRIC FURNACE
FUME
RETORTS
RETORTS
VACUUM DEZINCING KETTLE
ZINC
SLAG TO BLAST FURNACE
BULLION
STORAGE
H_2SO_4
CUPEL
CUPEL
NaOH
PbO
S
LEACH TANK
REFINING KETTLE
REFINING KETTLE
$NaNO_3$
SLAG TO BLAST FURNACE
CASTING
CASTING
FILTER
FINE SILVER TO MARKET
HARD LEAD TO MARKET
RESIDUE TO BLAST FURNACE
REFINED LEAD TO MARKET
ZINC
GOLD DORE TO MARKET
CADMIUM SPONGE TO ELECTROLYTIC REFINING
PRECIPITATION TANK
$ZnSO_4$ TO MARKET

Figure 7.6-1. Typical flowsheet of pyrometallurgical lead smelting.[2]

301<

eliminated in the slag. Solid products from the blast furnace generally separate into four layers: speiss (basically arsenic and antimony, the lightest material); matte (composed of copper sulfide and other metal sulfides); slag (primarily silicates); and lead bullion. The first three layers are combined as slag, which is continually collected from the furnace and either processed at the smelter for its metal content or shipped to treatment facilities.

A certain amount of SO_2 is also generated in blast furnaces due to the presence of small quantities of residual lead sulfide and lead sulfates in the sinter feed. The quantity of these emissions is a function of not only the residual sulfur content in the sinter, but of the amount of sulfur that is captured by copper and other impurities in the slag.

Rough lead bullion from the blast furnace usually requires preliminary treatment (drossing) in steel cast-iron kettles before undergoing refining operations. First, the bullion is cooled to 700 to 800°F; copper and small amounts of sulfur, arsenic, antimony, and nickel are removed from solution and collect on the surface as a dross. This dross, in turn, is treated in a reverberatory-type furnace where the copper and other metal impurities are further concentrated before being routed to copper smelters for their eventual recovery. Drossed lead bullion is further treated for copper removal by the addition of sulfur-bearing material and zinc and/or aluminum to lower the copper content to approximately 0.01 percent.

The final phase of smelting, the refining of the bullion is cast-iron kettles, occurs in five steps:

1. Removal of antimony, tin, and arsenic;
2. Removal of precious metals via the Parke's Process, in which zinc metal combines with gold and silver to form an insoluble intermetallic at operating temperatures;
3. Vacuum removal of zinc;
4. Bismuth removal using the Betterson Process, which involves the addition of calcium and magnesium, which in turn, form an insoluble compound with the bismuth that is skimmed from the kettle; and
5. Removal of remaining traces of metal impurities by addition of $NaOH$ and $NaNO_3$.

The final refined lead, commonly of 99.99 to 99.999 percent purity, is then cast into 100-pound pigs before shipment.

7.6.2 Emissions and Controls[1,2]

Each of the three major lead smelting operations generates substantial quantities of particulates and/or sulfur dioxide.

Nearly 85 percent of the sulfur present in the lead ore concentrate is eliminated in the sintering operation. In handling these process offgases, either a single weak stream is taken from the machine hood at less than 2 percent SO_2 or two streams are taken—one weak stream (<0.5 percent SO_2) from the discharge end of the machine and one strong stream (5 to 7 percent SO_2) taken from the feed end. Single stream operation is generally used when there is little or no market for the recovered sulfur, so that the uncontrolled weak SO_2 stream is emitted to the atmosphere. Where there is a potential sulfur market, however, the strong stream is sent to a sulfuric acid plant, and the weak stream is vented after particulate removal.

When dual gas stream operation is used with updraft sinter machines, the weak gas stream can be recirculated through the bed to mix with the strong gas stream, resulting in a single stream with an SO_2 concentration of about 6 percent. This technique has the overall effect of decreasing machine production capacity, but does permit a more convenient and economical recovery of the SO_2 via sulfuric acid plants and other control methods.

Without weak gas recirculation, the latter portion of the sinter machine acts as a cooling zone for the sinter and consequently assists in the reduction of dust formation during product discharge and screening. However, when recirculation is used, the sinter is usually discharged in a relatively hot state (400 to 500°C), with an attendant increase in particulate formation. Methods for reducing these dust quantities include recirculation of offgases through the sinter bed, relying upon the filtering effect of the latter, or ducting the gases from the discharge through a particulate collection device directly to the atmosphere. Because reaction activity has ceased in the discharge area in these cases, these latter gases contain little SO_2.

The particulate emissions from sinter machines consist of from 5 to 20 percent of the concentrated ore feed. When expressed in terms of product weight, these emissions are an estimated 106.5 kg/MT (213 lb/ton) of lead produced. This value, along with other particulate and SO_2 factors, appears in Table 7.6-1.

Table 7.6-1. EMISSION FACTORS FOR PRIMARY LEAD SMELTING PROCESSES WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: B

Process	Particulates		Sulfur dioxide	
	kg/MT	lb/ton	kg/MT	lb/ton
Ore crushing[b]	1.0	2.0	–	–
Sintering (updraft)[c]	106.5	213.0	275.0	550.0
Blast furnace[b]	180.5	361.0	22.5	45.0
Dross reverberatory furnace[b]	10.0	20.0	Neg	Neg
Materials handling[b]	2.5	5.0	–	–

[a] Ore crushing emission factors expressed as kg/MT (lb/ton) of crushed ore; all other emission factors expressed as kg/MT (lb/ton) of lead product.

[b] Reference 2.

[c] References 1, 4, 5, and 6.

[d] References 1, 2, and 7.

Typical material balances from domestic lead smelters indicate that about 10 to 20 percent of the sulfur in the ore concentrate fed to the sinter machine is eliminated in the blast furnace. However, only *half* of this amount (about 7 percent of the total) is emitted as SO_2; the remainder is captured by the slag. The concentration of this SO_2 stream can vary from 500 to 2500 ppm by volume, depending on the amount of dilution air injected to oxidize the carbon monoxide and cool the stream before baghouse treatment for particulate removal.

Particulate emissions from blast furnaces contain many different kinds of material, including a range of lead oxides, quartz, limestone, iron pyrites, iron-lime-silicate slag, arsenic, and other metals-containing compounds associated with lead ores. These particles readily agglomerate, are primarily submicron in size, difficult to wet, cohesive, and will bridge and arch in hoppers. On the average, this dust loading is quite substantial (see Table 7.6-1).

Virtually no sulfur dioxide emissions are associated with the various refining operations. However, a small amount of particulates is generated by the dross reverberatory furnace (10 kg/MT of lead).

Finally, minor quantities of particulates are generated by ore crushing and materials handling operations. These emission factors are also presented in Table 7.6-1.

Methods used to control emission from lead smelter operations fall into two broad categories–particulate and sulfur dioxide control techniques. The most commonly employed high-efficiency particulate control devices are fabric filters and electrostatic precipitators, which, in turn, often follow centrifugal collectors and tubular coolers (pseudogravity collectors). Three of the six lead smelters presently operating in the United States use single absorption sulfuric acid plants for control of sulfur dioxide emissions from sinter machines and, occasionally, blast furnaces. Other technically feasible SO_2 control methods are elemental sulfur recovery plants and dimethylaniline (DMA) and ammonia absorption processes. These methods and their representative control efficiencies are listed in Table 7.6-2.

Table 7.6-2. EFFICIENCIES OF REPRESENTATIVE CONTROL DEVICES USED WITH PRIMARY LEAD SMELTING OPERATIONS

Control device or method	Control device efficiency range	
	Particulates	Sulfur dioxide
Centrifugal collector (e.g., cyclone)[a]	80 to 90	–
Electrostatic precipitator[a]	95 to 99	–
Fabric filter[a]	95 to 99	–
Tubular cooler (associated with waste heat boiler)[a]	70 to 80	–
Sulfuric acid plant (single contact)[b,c]	99.5 to 99.9	96 to 97
Elemental sulfur recovery plant[b,d]	–	90
Dimethylaniline (DMA) absorption process[b,e]	–	95 to 98.8
Ammonia absorption process[b,f]	–	92 to 95.2

[a] Reference 2.

[b] Reference 1.

[c] High particulate control efficiency due to action of acid plant gas precleaning system. Range of SO_2 efficiencies based on inlet and outlet concentrations of 5 to 7 percent and 2000 ppm, respectively.

[d] Collection efficiency for a two-stage, uncontrolled Claus-type plant. Refer to Section 5.18 for more information.

[e] Range of SO_2 efficiencies based on inlet and outlet concentrations of 4 to 6 percent and 500 to 3000 ppm, respectively.

[f] Range of SO_2 efficiencies based on inlet and outlet concentrations of 1.5 to 2.5 percent and 1200 ppm, respectively.

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7.7 ZINC SMELTING

7.7.1 Process Description[1,2]

As stated previously, most domestic zinc comes from zinc and lead ores. Another important source of raw material for zinc metal has been zinc oxide from fuming furnaces. For efficient recovery of zinc, sulfur must be removed from concentrates to a level of less than 2 percent. This is done by fluidized beds or multiple-hearth roasting occasionally followed by sintering. Metallic zinc can be produced from the roasted ore by the horizontal or vertical retort process or by the electrolytic process if a high-purity zinc is needed.

7.7.2 Emissions and Controls[1,2]

Dust, fumes, and sulfur dioxide are emitted from zinc concentrate roasting or sintering operations. Particulates may be removed by electrostatic precipitators or baghouses. Sulfur dioxide may be converted directly into sulfuric acid or vented. Emission factors for zinc smelting are presented in Table 7.7-1.

Table 7.7-1. EMISSION FACTORS FOR PRIMARY ZINC SMELTING WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: B

Type of operation	Particulates		Sulfur oxides	
	lb/ton	kg/MT	lb/ton	kg/MT
Roasting (multiple-hearth)[b]	120	60	1100	550
Sintering[c]	90	45	d	d
Horizontal retorts[e]	8	4	–	–
Vertical retorts[e]	100	50	–	–
Electrolytic process	3	1.5	–	–

[a] Approximately 2 unit weights of concentrated ore are required to produce 1 unit weight of zinc metal. Emission factors expressed as units per unit weight of concentrated ore produced.

[b] References 3 and 4.

[c] References 2 and 3.

[d] Included in SO_2 losses from roasting.

[e] Reference 3.

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7.8 SECONDARY ALUMINUM OPERATIONS

7.8.1 Process Description[1,2]

Secondary aluminum operations involve making lightweight metal alloys for industrial castings and ingots. Copper, magnesium, and silicon are the most common alloying constituents. Aluminum alloys for castings are melted in small crucible furnaces charged by hand with pigs and foundry returns. Larger melting operations use open-hearth reverberatory furnaces charged with the same type of materials but by mechanical means. Small operations sometimes use sweating furnaces to treat dirty scrap in preparation for smelting.

To produce a high-quality aluminum product, fluxing is practiced to some extent in all secondary aluminum melting. Aluminum fluxes are expected to remove dissolved gases and oxide particles from the molten bath. Sodium and various mixtures of potassium or sodium chloride with cryolite and chlorides of aluminum zinc are used as fluxes. Chlorine gas is usually lanced into the molten bath to reduce the magnesium content by reacting to form magnesium and aluminum chlorides.[3,4]

7.8.2 Emissions[2]

Emissions from secondary aluminum operations include fine particulate matter and gaseous chlorine. A large part of the material charged to a reverberatory furnace is low-grade scrap and chips. Paint, dirt, oil, grease, and other contaminants from this scrap cause large quantities of smoke and fumes to be discharged. Even if the scrap is clean, large surface-to-volume ratios require the use of more fluxes, which can cause serious air pollution problems. Table 7.8-1 presents particulate emission factors for secondary aluminum operations.

Table 7.8-1. PARTICULATE EMISSION FACTORS FOR SECONDARY ALUMINUM OPERATIONS[a]
EMISSION FACTOR RATING: B

Type of operation	Uncontrolled		Baghouse		Electrostatic precipitator	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Sweating furnace	14.5	7.25	3.3	1.65	–	–
Smelting						
Crucible furnace	1.9	0.95	–	–	–	–
Reverberatory furnace	4.3	2.15	1.3	0.65	1.3	0.65
Chlorination station[b]	1000	500	50	25	–	–

[a] Reference 5. Emission factors expressed as units per unit weight of metal processed.
[b] Pounds per ton (kg/MT) of chlorine used.

367<

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7.9 BRASS AND BRONZE INGOTS (COPPER ALLOYS)

7.9.1 Process Description[1]

Obsolete domestic and industrial copper-bearing scrap is the basic raw material of the brass and bronze ingot industry. The scrap frequently contains any number of metallic and nonmetallic impurities, which can be removed by such methods as hand sorting, magnetizing, heat methods such as sweating or burning, and gravity separation in a water medium.

Brass and bronze ingots are produced from a number of different furnaces through a combination of melting, smelting, refining, and alloying of the processed scrap material. Reverberatory, rotary, and crucible furnaces are the ones most widely used, and the choice depends on the size of the melt and the alloy desired. Both the reverberatory and the rotary furnaces are normally heated by direct firing, in which the flame and gases come into direct contact with the melt. Processing is essentially the same in any furnace except for the differences in the types of alloy being handled. Crucible furnaces are usually much smaller and are used principally for special-purpose alloys.

7.9.2 Emissions and Controls[1]

The principal source of emissions in the brass and bronze ingot industry is the refining furnace. The exit gas from the furnace may contain the normal combustion products such as fly ash, soot, and smoke. Appreciable amounts of zinc oxide are also present in this exit gas. Other sources of particulate emissions include the preparation of raw materials and the pouring of ingots.

The only air pollution control equipment that is generally accepted in the brass and bronze ingot industry is the baghouse filter, which can reduce emissions by as much as 99.9 percent. Table 7.9-1 summarizes uncontrolled emissions from various brass and bronze melting furnaces.

Table 7.9-1. PARTICULATE EMISSION FACTORS FOR BRASS AND BRONZE MELTING FURNACES WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: A

Type of furnace	Uncontrolled emissions[b]	
	lb/ton	kg/MT
Blast[c]	18	9
Crucible	12	6
Cupola	73	36.5
Electric induction	2	1
Reverberatory	70	35
Rotary	60	30

[a] Reference 1. Emission factors expressed as units per unit weight of metal charged.

[b] The use of a baghouse can reduce emissions by 95 to 99.6 percent.

[c] Represents emissions following precleaner.

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7.10 GRAY IRON FOUNDRY

7.10.1 Process Description[1]

Three types of furnaces are used to produce gray iron castings: cupolas, reverberatory furnaces, and electric induction furnaces. The cupola is the major source of molten iron for the production of castings. In operation, a bed of coke is placed over the sand bottom in the cupola. After the bed of coke has begun to burn properly, alternate layers of coke, flux, and metal are charged into the cupola. Combustion air is forced into the cupola, causing the coke to burn and melt the iron. The molten iron flows out through a taphole.

Electric furnaces are commonly used where special alloys are to be made. Pig iron and scrap iron are charged to the furnace and melted, and alloying elements and fluxes are added at specific intervals. Induction furnaces are used where high-quality, clean metal is available for charging.

7.10.2 Emissions[1]

Emissions from cupola furnaces include gases, dust, fumes, and smoke and oil vapors. Dust arises from dirt on the metal charge and from fines in the coke and limestone charge. Smoke and oil vapor arise primarily from the partial combustion and distillation of oil from greasy scrap charged to the furnace. Also, the effluent from the cupola furnace has a high carbon monoxide content that can be controlled by an afterburner. Emissions from reverberatory and electric induction furnaces consist primarily of metallurgical fumes and are relatively low. Table 7.10-1 presents emission factors for the manufacture of iron castings.

Table 7.10-1. EMISSION FACTORS FOR GRAY IRON FOUNDRIES[a,b,c]
EMISSION FACTOR RATING: B

Type of furnace	Particulates		Carbon monoxide	
	lb/ton	kg/MT	lb/ton	kg/MT
Cupola				
Uncontrolled	17	8.5	145[c,d]	72.5[c,d]
Wet cap	8	4	–	–
Impingement scrubber	5	2.5	–	–
High-energy scrubber	0.8	0.4	–	–
Electrostatic precipitator	0.6	0.3	–	–
Baghouse	0.2	0.1	–	–
Reverberatory	2	1	–	–
Electric induction	1.5	0.75	–	–

[a] References 2 through 5. Emission factors expressed as units per unit weight of metal charged.

[b] Approximately 85 percent of the total charge is metal. For every unit weight of coke in the charge, 7 unit weights of gray iron are produced.

[c] Reference 6.

[d] A well-designed afterburner can reduce emissions to 9 pounds per ton (4.5 kg/MT) of metal charged.[2]

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7.11 SECONDARY LEAD SMELTING

Revised by William M. Vatavuk

7.11.1 Process Description [1-3]

In the secondary smelting, refining, and alloying of lead, the three types of furnace most commonly used are reverberatory, blast or cupola, and pot. The grade of metal to be produced–soft, semisoft, or hard–dictates the type of funace to be used.

Used for the production of semisoft lead, the reverberatory furnace reclaims this metal from a charge of lead scrap, battery plates, oxides, drosses, and lead residues. The furnace consists of an outer shell built in the shape of a rectangular box lined with refractory brick. To provide heat for melting, the charge gas or oil-fired burners are usually placed at one end of the furnace, and the material to be melted is charged through an opening in the shell.

The charge is placed in the furnace in such a manner as to keep a small mound of unmelted material on top of the bath. Continuously, as this mound becomes molten at the operating temperature (approximately 1250°C), more material is charged. Semisoft lead is tapped off periodically as the level of the metal rises in the furnace. The amount of metal recovered is about 50 to 60 kilograms per square meter of hearth area per hour.

A similar kind of furnace–the revolving (rotary) reverberatory–is used at several European installations for the recovery of lead from battery scrap and lead sulfate sludge. Its charge makeup and operating characteristics are identical to the reverberatories used in the United States, except that the furnace slowly revolves as the charge is heated.

The blast (cupola) furnace, used to produce "hard" lead, is normally charged with the following: rerun slag from previous runs (4.5 percent); cast-iron scrap (4.5 percent); limestone (3 percent); coke (5.5 percent); and drosses from pot furnace refining, oxides, and reverberatory slag (82.5 percent). Similar to an iron cupola, the furnace consists of a steel sheet lined with refractory material. Air, under high pressure, is introduced at the bottom through tuyeres to permit combustion of the coke, which provides the heat and a reducing atmosphere.

As the charge material melts, limestone and iron form an oxidation-retardant flux that floats to the top, and the molten lead flows from the furnace into a holding pot at a nearly continuous rate. The rest (30 percent) of the tapped molten material is slag, 5 percent of which is retained for later rerun. From the holding pot, the lead is usually cast into large ingots called "buttons" or "sows."

Pot-type furnaces are used for remelting, alloying, and refining processes. These furnaces are usually gas fired and range in size from 1 to 45 metric tons capacity. Their operation consists simply of charging ingots of lead or alloy material and firing the charge until the desired product quality is obtained.

Refining processes most commonly employed are those for the removal of copper and antimony to produce soft lead, and those for the removal of arsenic, copper, and nickel to produce hard lead.

Figure 7.11-1 illustrates these three secondary lead smelting processes.

7.11.2 Emissions and Controls [1,2]

The emissions and controls from secondary lead smelting processes may be conveniently considered according to the type of furnace employed.

With the reverberatory furnaces, the temperature maintained is high enough to oxidize the sulfides present in the charge to sulfur dioxide and sulfur trioxide, which, in turn, are emitted in the exit gas. Also emitted are such particulates (at concentrations of 16 to 50 grams per cubic meter) as oxides, sulfides, and sulfates of lead, tin,

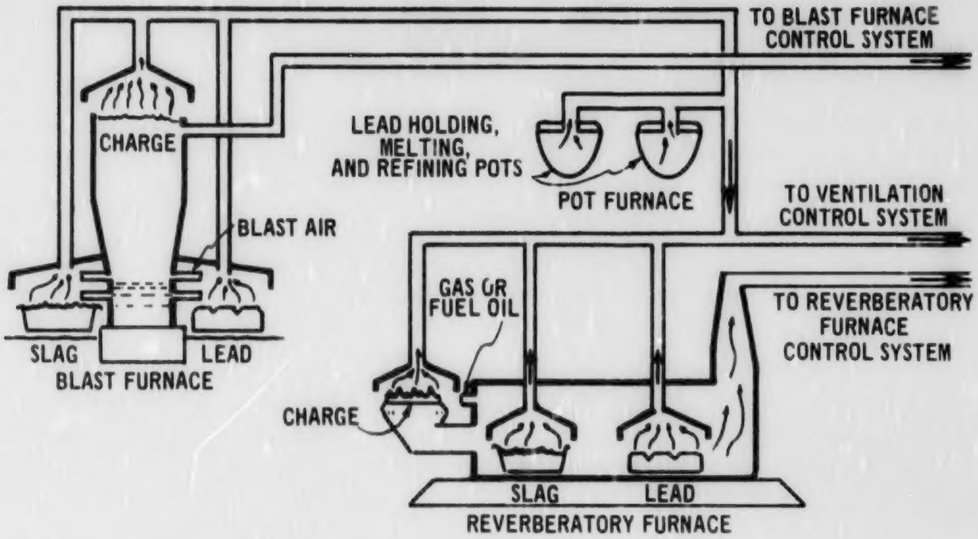
TO BLAST FURNACE
CONTROL SYSTEM
CHARGE
LEAD HOLDING,
MELTING,
AND REFINING POTS
POT FURNACE
BLAST AIR
TO VENTILATION
CONTROL SYSTEM
GAS OR
FUEL OIL
TO REVERBERATORY
FURNACE
CONTROL SYSTEM
SLAG
LEAD
BLAST FURNACE
CHARGE
SLAG
LEAD
REVERBERATORY FURNACE

Figure 7.11-1. Secondary lead smelter processes.[4]

arsenic, copper, and antimony. The particles are nearly spherical and tend to agglomerate. Emission factors for reverberatory furnaces are presented in Table 7.11-1.

The most practical control system for a reverberatory furnace consists of a gas settling/cooling chamber and a fabric filter. This system effects a particulate removal of well in excess of 99 percent. Because of the potential presence of sparks and flammable material, a great deal of care is taken to control the temperature of the gas stream. In turn, the type of filter cloth selected depends upon stream temperature and such parameters as gas

Table 7.11-1. EMISSION FACTORS FOR SECONDARY LEAD SMELTING FURNACES WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: B

Furnace type	Particulates		Sulfur dioxide	
	kg/MT	lb/ ton	kg/MT	lb/ton
Reverberatory[b]	73.5 (28.0 to 156.5)[c]	147 (56 to 313)	40.0 (35.5 to 44.0)	80 (71 to 88)
Blast (cupola)[d]	96.5 (10.5 to 190.5)	193 (21.0 to 381.0)	26.5 (9.0 to 55.0)	53.0 (18 to 110)
Pot[e]	0.4	0.8	Neg	Neg
Rotary reverberatory[f]	35.0	70.0	NA[g]	NA[g]

[a] All emission factors expressed in terms of kg/MT and lb/ton of metal charged to furnace.

[b] References 2, 5 through 7.

[c] Numbers in parentheses represent ranges of values obtained.

[d] References 2, 7 through 9.

[e] Reference 7.

[f] Reference 3.

[g] NA—no data available to make estimates.

stream corrosivity and the permeability and abrasion (or stress)-resisting characteristics of the cloth. In any case, the filtering velocity seldom exceeds 0.6 m/min. Table 7.11-2 offers a listing of control devices and their efficiencies.

Table 7.11-2. EFFICIENCIES OF PARTICULATE CONTROL EQUIPMENT ASSOCIATED WITH SECONDARY LEAD SMELTING FURNACES

Control device	Furnace type	Particulate control efficiency
Fabric filter[a]	Blast	98.4
	Reverberatory	99.2
Dry cyclone plus fabric filter[a]	Blast	99.0
Wet cyclone plus fabric filter[b]	Reverberatory	99.7
Settling chamber plus dry cyclone plus fabric filter[c]	Reverberatory	99.8
Venturi scrubber plus demister[d]	Blast	99.3

[a] Reference 2.
[b] Reference 5.
[c] Reference 6.
[d] Reference 8.

Combustion air from the tuyeres passing through the blast furnace charge conveys metal oxides, bits of coke, and other particulates present in the charge. The particulate is roughly 7 percent by weight of the total charge (up to 44 g/m^3). In addition to particulates, the stack gases also contain carbon monoxide. However, the carbon monoxide and any volatile hydrocarbons present are oxidized to carbon dioxide and water in the upper portion of the furnace, which effectively acts as an afterburner.

Fabric filters, preceded by radiant cooling columns, evaporative water coolers, or air dilution jets, are also used to control blast furnace particulates. Overall efficiencies exceeding 95 percent are common (see Table 7.11-2). Representative size distributions of particles in blast and reverberatory furnace streams are presented in Table 7.11-3.

Compared with the other furnace types, pot furnace emissions are low (see Table 7.11-1). However, to maintain a hygienic working environment, pot furnace off gases, usually along with emission streams from other furnaces, are directed to fabric filter systems.

Table 7.11-3. REPRESENTATIVE PARTICLE SIZE DISTRIBUTION FROM A COMBINED BLAST AND REVERBERATORY FURNACE GAS STREAM[a]

Size range, μm	Fabric filter catch, wt %
0 to 1	13.3
1 to 2	45.2
2 to 3	19.1
3 to 4	14.0
4 to 16	8.4

[a] Reference 1.
[b] These particles are distributed log-normally, according to the following frequency distribution:

$$f(D) = 1.56 \exp\left[\frac{-(\log D - 0.262)^2}{0.131}\right]$$

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7.12 SECONDARY MAGNESIUM SMELTING

7.12.1 Process Description[1]

Magnesium smelting is carried out in crucible or pot-type furnaces that are charged with magnesium scrap and fired by gas, oil, or electric heating. A flux is used to cover the surface of the molten metal because magnesium will burn in air at the pouring temperature (approximately 1500°F or 815°C). The molten magnesium, usually cast by pouring into molds, is annealed in ovens utilizing an atmosphere devoid of oxygen.

7.12.2 Emissions[1]

Emissions from magnesium smelting include particulate magnesium (MgO) from the melting, nitrogen oxides from the fixation of atmospheric nitrogen by the furnace temperatures, and sulfur dioxide losses from annealing oven atmospheres. Factors affecting emissions include the capacity of the furnace; the type of flux used on the molten material; the amount of lancing used; the amount of contamination of the scrap, including oil and other hydrocarbons; and the type and extent of control equipment used on the process. The emission factors for a pot furnace are shown in Table 7.12-1.

Table 7.12-1. EMISSION FACTORS FOR MAGNESIUM SMELTING
EMISSION FACTOR RATING: C

Type of furnace	Particulates[a]	
	lb/ton	kg/MT
Pot furnace		
Uncontrolled	4	2
Controlled	0.4	0.2

[a] References 2 and 3. Emission factors expressed as units per unit weight of metal processed.

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7.13 STEEL FOUNDRIES

7.13.1 Process Description[1]

Steel foundries produce steel castings by melting steel metal and pouring it into molds. The melting of steel for castings is accomplished in one of five types of furnaces: direct electric-arc, electric induction, open-hearth, crucible, and pneumatic converter. The crucible and pneumatic converter are not in widespread use, so this section deals only with the remaining three types of furnaces. Raw materials supplied to the various melting furnaces include steel scrap of all types, pig iron, ferroalloys, and limestone. The basic melting process operations are furnace charging, melting, tapping the furnace into a ladle, and pouring the steel into molds. An integral part of the steel foundry operation is the preparation of casting molds, and the shakeout and cleaning of these castings. Some common materials used in molds and cores for hollow casting include sand, oil, clay, and resin. Shakeout is the operation by which the cool casting is separated from the mold. The castings are commonly cleaned by shot-blasting, and surface defects such as fins are removed by burning and grinding.

7.13 Emissions[1]

Particulate emissions from steel foundry operations include iron oxide fumes, sand fines, graphite, and metal dust. Gaseous emissions from foundry operations include oxides of nitrogen, oxides of sulfur, and hydrocarbons. Factors affecting emissions from the melting process include the quality and cleanliness of the scrap and the amount of oxygen lancing. The concentrations of oxides of nitrogen are dependent upon operating conditions in the melting unit, such as temperature and the rate of cooling of the exhaust gases. The concentration of carbon monoxide in the exhaust gases is dependent on the amount of draft on the melting furnace. Emissions from the shakeout and cleaning operations, mostly particulate matter, vary according to type and efficiency of dust collection. Gaseous emissions from the mold and baking operations are dependent upon the fuel used by the ovens and the temperature reached in these ovens. Table 7.13-1 summarizes the emission factors for steel foundries.

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Table 7.13-1. EMISSION FACTORS FOR STEEL FOUNDRIES
EMISSION FACTOR RATING: A

Type of process	Particulates[a]		Nitrogen oxides	
	lb/ton	kg/MT	lb/ton	kg/MT
Melting				
Electric arc[b,c]	13 (4 to 40)	6.5 (2 to 20)	0.2	0.1
Open-hearth[d,e]	11 (2 to 20)	5.5 (1 to 10)	0.01	0.005
Open-hearth oxygen lanced[f,g]	10 (8 to 11)	5 (4 to 5.5)	–	–
Electric induction[h]	0.1	0.05	–	–

[a] Emission factors expressed as units per unit weight of metal processed. If the scrap metal is very dirty or oily, or if increased oxygen lancing is employed, the emission factor should be chosen from the high side of the factor range.

[b] Electrostatic precipitator, 92 to 98 percent control efficiency; baghouse (fabric filter), 98 to 99 percent control efficiency; venturi scrubber, 94 to 98 percent control efficiency.

[c] References 2 through 11.

[d] Electrostatic precipitator, 95 to 98.5 percent control efficiency; baghouse, 99.9 percent control efficiency; venturi scrubber, 96 to 99 percent control efficiency.

[e] References 2 and 12 through 14.

[f] Electrostatic precipitator, 95 to 98 percent control efficiency; baghouse, 99 percent control efficiency; venturi scrubber, 95 to 98 percent control efficiency.

[g] References 7 and 15.

[h] Usually not controlled.

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7.14 SECONDARY ZINC PROCESSING

7.14.1 Process Description[1]

Zinc processing includes zinc reclaiming, zinc oxide manufacturing, and zinc galvanizing. Zinc is separated from scrap containing lead, copper, aluminum, and iron by careful control of temperature in the furnace, allowing each metal to be removed at its melting range. The furnaces typically employed are the pot, muffle, reverberatory, or electric induction. Further refining of the zinc can be done in retort distilling or vaporization furnaces where the vaporized zinc is condensed to the pure metallic form. Zinc oxide is produced by distilling metallic zinc into a dry air stream and capturing the subsequently formed oxide in a baghouse. Zinc galvanizing is carried out in a vat or in bath-type dip tanks utilizing a flux cover. Iron and steel pieces to be coated are cleaned and dipped into the vat through the covering flux.

7.14.2 Emissions[1]

A potential for particulate emissions, mainly zinc oxide, occurs if the temperature of the furnace exceeds 1100°F (595°C). Zinc oxide (ZnO) may escape from condensers or distilling furnaces, and because of its extremely small particle size (0.03 to 0.5 micron), it may pass through even the most efficient collection systems. Some loss of zinc oxides occurs during the galvanizing processes, but these losses are small because of the flux cover on the bath and the relatively low temperature maintained in the bath. Some emissions of particulate ammonium chloride occur when galvanized parts are dusted after coating to improve their finish. Another potential source of emissions of particulates and gaseous zinc is the tapping of zinc-vaporizing muffle furnaces to remove accumulated slag residue. Emissions of carbon monoxide occur when zinc oxide is reduced by carbon. Nitrogen oxide emissions are also possible because of the high temperature associated with the smelting and the resulting fixation of atmospheric nitrogen. Table 7.14-1 summarizes the emission factors from zinc processing.

Table 7.14-1. PARTICULATE EMISSION FACTORS FOR
SECONDARY ZINC SMELTING[a]
EMISSION FACTOR RATING: C

Type of furnace	Emissions	
	lb/ton	kg/MT
Retort reduction	47	23.5
Horizontal muffle	45	22.5
Pot furnace	0.1	0.05
Kettle sweat furnace processing[b]		
Clean metallic scrap	Neg	Neg
General metallic scrap	11	5.5
Residual scrap	25	12.5
Reverberatory sweat furnace processing[b]		
Clean metallic scrap	Neg	Neg
General metallic scrap	13	6.5
Residual scrap	32	16
Galvanizing kettles	5	2.5
Calcining kiln	89	44.5

[a] References 2 through 4. Emission factors expressed as units per unit weight of metal produced.

[b] Reference 5.

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8. MINERAL PRODUCTS INDUSTRY

This section involves the processing and production of various minerals. Mineral processing is characterized by particulate emissions in the form of dust. Frequently, as in the case of crushing and screening, this dust is identical to the material being handled. Emissions also occur through handling and storing the finished product because this material is often dry and fine. Particulate emissions from some of the processes such as quarrying, yard storage, and dust from transport are difficult to control. Most of the emissions from the manufacturing processes discussed in this section, however, can be reduced by conventional particulate control equipment such as cyclones, scrubbers, and fabric filters. Because of the wide variety in processing equipment and final product, emissions cover a wide range; however, average emission factors have been presented for general use.

8.1 ASPHALTIC CONCRETE PLANTS

Revised by Dennis H. Ackerson
and James H. Southerland

8.1.1 Process Description

Selecting and handling the raw material is the first step in the production of asphaltic concrete, a paving substance composed of a combination of aggregates uniformly mixed and coated with asphalt cement. Different applications of asphaltic concrete require different aggregate size distributions, so that the raw aggregates are crushed and screened at the quarries. The coarse aggregate usually consists of crushed stone and gravel, but waste materials, such as slag from steel mills or crushed glass, can be used as raw material.

Plants produce finished asphaltic concrete through either batch (Figure 8.1-1) or continuous (Figure 8.1-2) aggregate mixing operations. The raw aggregate is normally stock-piled near the plant at a location where the moisture content will stabilize between 3 and 5 percent by weight.

As processing for either type of operation begins, the aggregate is hauled from the storage piles and placed in the appropriate hoppers of the cold-feed unit. The material is metered from the hoppers onto a conveyor belt and is transported into a gas- or oil-fired rotary dryer. Because a substantial portion of the heat is transferred by radiation, dryers are equipped with flights that are designed to tumble the aggregate and promote drying.

As it leaves the dryer, the hot material drops into a bucket elevator and is transferred to a set of vibrating screens where it is classified by size into as many as four different grades. At this point it enters the mixing operation.

In a batch plant, the classified aggregate drops into one of four large bins. The operator controls the aggregate size distribution by opening individual bins and allowing the classified aggregate to drop into a weigh hopper until the desired weight is obtained. After all the material is weighed out, the sized aggregates are dropped into a mixer and mixed dry for about 30 seconds. The asphalt, which is a solid at ambient temperatures, is pumped from heated storage tanks, weighed, and then injected into the mixer. The hot, mixed batch is then dropped into a truck and hauled to the job site.

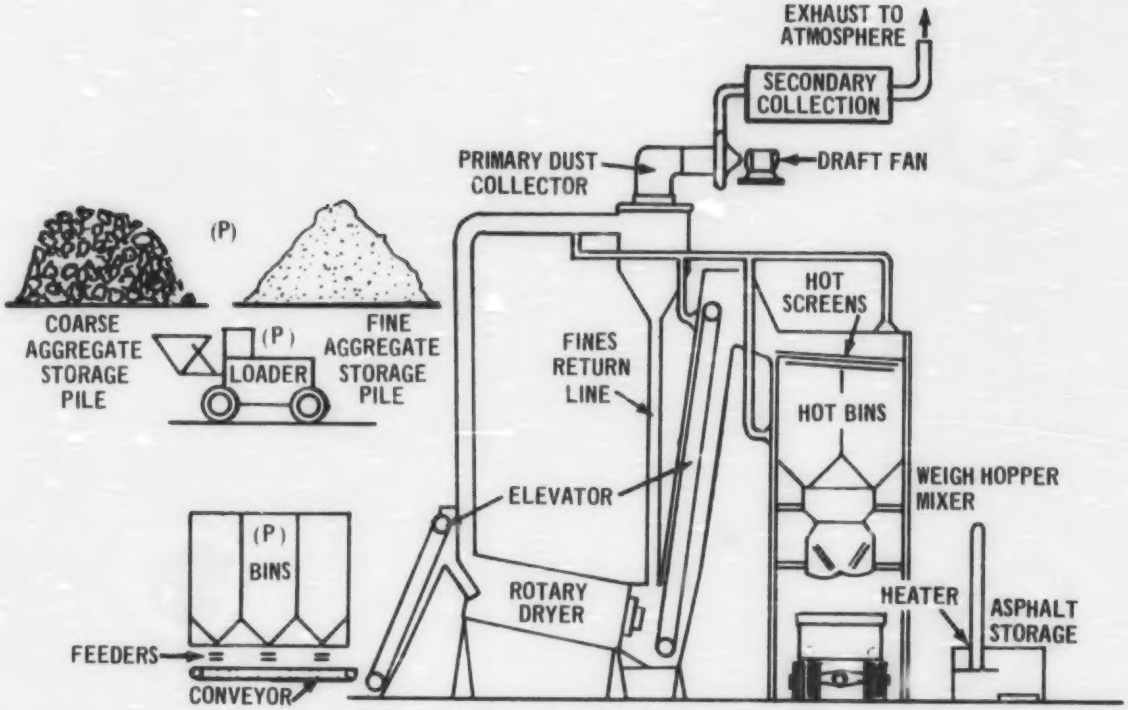
EXHAUST TO ATMOSPHERE
SECONDARY COLLECTION
PRIMARY DUST COLLECTOR
DRAFT FAN
(P)
COARSE AGGREGATE STORAGE PILE
FINE AGGREGATE STORAGE PILE
(P)
LOADER
FINES RETURN LINE
HOT SCREENS
HOT BINS
ELEVATOR
WEIGH HOPPER MIXER
(P)
BINS
ROTARY DRYER
HEATER
ASPHALT STORAGE
FEEDERS
CONVEYOR

Figure 8.1-1. Batch hot-mix asphalt plant. "P" denotes particulate emission points.[1]

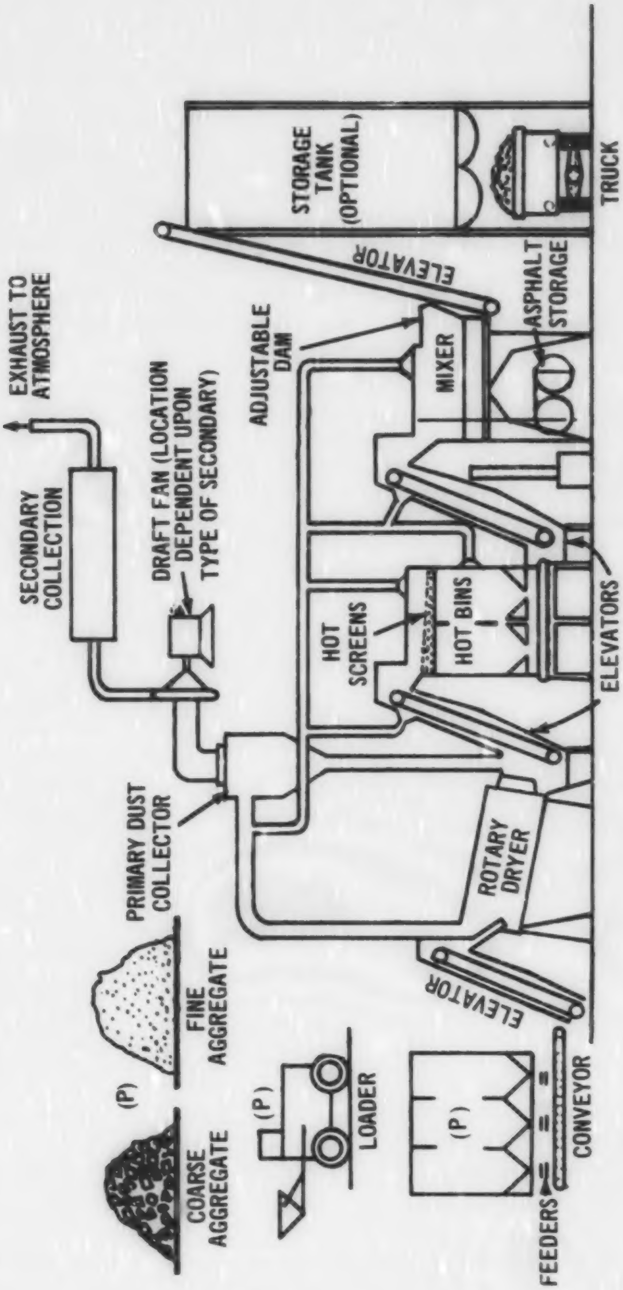
EXHAUST TO ATMOSPHERE
SECONDARY COLLECTION
DRAFT FAN (LOCATION DEPENDENT UPON TYPE OF SECONDARY)
PRIMARY DUST COLLECTOR
(P)
COARSE AGGREGATE
FINE AGGREGATE
(P)
LOADER
(P)
FEEDERS
CONVEYOR
ELEVATOR
ROTARY DRYER
HOT SCREENS
HOT BINS
ELEVATORS
ADJUSTABLE DAM
MIXER
ASPHALT STORAGE
ELEVATOR
STORAGE TANK (OPTIONAL)
TRUCK

Figure 8.1-2. Continous hot-mix asphalt plant. "P" denotes particulate emission points.[1]

In a continuous plant, the classified aggregate drops into a set of small bins, which collect and meter the classified aggregate to the mixer. From the hot bins, the aggregate is metered through a set of feeder conveyors to another bucket elevator and into the mixer. Asphalt is metered into the inlet end of the mixer, and retention time is controlled by an adjustable dam at the end of the mixer. The mix flows out of the mixer into a hopper from which the trucks are loaded.

8.1.2 Emissions and Controls[3,4]

Dust sources are the rotary dryer; the hot aggregate elevators; the vibrating screens; and the hot-aggregate storage bins, weigh hoppers, mixers, and transfer points. The largest dust emission source is the rotary dryer. In some plants, the dust from the dryer is handled separately from emissions from the other sources. More commonly, however, the dryer, its vent lines, and other fugitive sources are treated in combination by a single collector and fan system.

The choice of applicable control equipment ranges from dry, mechanical collectors to scrubbers and fabric collectors; attempts to apply electrostatic precipitators have met with little success. Practically all plants use primary dust collection equipment, such as large diameter cyclone, skimmer, or settling chambers. These chambers are often used as classifiers with the collected materials being returned to the hot aggregate elevator to combine with the dryer aggregate load. The air discharge from the primary collector is seldom vented to the atmosphere because high emission levels would result. The primary collector effluent is therefore ducted to a secondary or even to a tertiary collection device.

Emission factors for asphaltic concrete plants are presented in Table 8.1-1. Particle size information has not been included because the particle size distribution varies with the aggregate being used, the mix being made, and the type of plant operation.

Table 8.1-1. PARTICULATE EMISSION FACTORS
FOR ASPHALTIC CONCRETE PLANTS[a]
EMISSION FACTOR RATING: A

Type of control	Emissions lb/ton	Emissions kg/MT
Uncontrolled[b]	45.0	22.5
Precleaner	15.0	7.5
High-efficiency cyclone	1.7	0.85
Spray tower	0.4	0.20
Multiple centrifugal scrubber	0.3	0.15
Baffle spray tower	0.3	0.15
Orifice-type scrubber	0.04	0.02
Baghouse[c]	0.1	0.05

[a] References 1, 2, and 5 through 10.

[b] Almost all plants have at least a precleaner following the rotary dryer.

[c] Emissions from a properly designed, installed, operated, and maintained collector can be as low as 0.005 to 0.020 lb/ton (0.0025 to 0.010 kg/MT).

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8.2 ASPHALT ROOFING

8.2.1 Process Description[1]

The manufacture of asphalt roofing felts and shingles involves saturating fiber media with asphalt by means of dipping and/or spraying. Although it is not always done at the same site, preparation of the asphalt saturant is an integral part of the operation. This preparation, called "blowing," consists of oxidizing the asphalt by bubbling air through the liquid asphalt for 8 to 16 hours. The saturant is then transported to the saturation tank or spray area. The saturation of the felts is accomplished by dipping, high-pressure sprays, or both. The final felts are made in various weights: 15, 30, and 55 pounds per 100 square feet (0.72, 1.5, and 2.7 kg/m^2). Regardless of the weight of the final product, the makeup is approximately 40 percent dry felt and 60 percent asphalt saturant.

8.2.2 Emissions and Controls[1]

The major sources of particulate emissions from asphalt roofing plants are the asphalt blowing operations and the felt saturation. Another minor source of particulates is the covering of the roofing material with roofing granules. Gaseous emissions from the saturation process have not been measured but are thought to be slight because of the initial driving off of contaminants during the blowing process.

A common method of control at asphalt saturating plants is the complete enclosure of the spray area and saturator with good ventilation through one or more collection devices, which include combinations of wet scrubbers and two-stage low-voltage electrical precipitators, or cyclones and fabric filters. Emission factors for asphalt roofing are presented in Table 8.2-1.

Table 8.2-1. EMISSION FACTORS FOR ASPHALT ROOFING MANUFACTURING WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: D

Operation	Particulates[b]		Carbon monoxide		Hydrocarbons (CH_4)	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Asphalt blowing[c]	2.5	1.25	0.9	0.45	1.5	0.75
Felt saturation[d]						
Dipping only	1	0.5	–	–	–	–
Spraying only	3	1.5	–	–	–	–
Dipping and spraying	2	1	–	–	–	–

[a] Approximately 0.65 unit of asphalt input is required to produce 1 unit of saturated felt. Emission factors expressed as units per unit weight of saturated felt produced.

[b] Low-voltage precipitators can reduce emissions by about 60 percent; when they are used in combination with a scrubber, overall efficiency is about 85 percent.

[c] Reference 2.

[d] References 3 and 4.

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8.3 BRICKS AND RELATED CLAY PRODUCTS

Revised by Dennis H. Ackerson

8.3.1 Process Description

The manufacture of brick and related products such as clay pipe, pottery, and some types of refractory brick involves the mining, grinding, screening, and blending of the raw materials, and the forming, cutting or shaping, drying or curing, and firing of the final product.

Surface clays and shales are mined in open pits; most fine clays are found underground. After mining, the material is crushed to remove stones and stirred before it passes onto screens that are used to segregate the particles by size.

At the start of the forming process, clay is mixed with water, usually in a pug mill. The three principal processes for forming brick are: stiff-mud, soft-mud, and dry-process. In the stiff-mud process, sufficient water is added to give the clay plasticity; bricks are then formed by forcing the clay through a die and using cutter wire to separate the bricks. All structural tile and most brick are formed by this process. The soft-mud process is usually used when the clay contains too much water for the stiff-mud process. The clay is mixed with water until the moisture content reaches 20 to 30 percent, and the bricks are formed in molds. In the dry-press process, clay is mixed with a small amount of water and formed in steel molds by applying a pressure of 500 to 1500 psi. The brick manufacturing process is shown in Figure 8.3-1.

Before firing, the wet clay units that have been formed are almost completely dried in driers that are usually heated by waste heat from the kilns. Many types of kilns are used for firing brick; however, the most common are the tunnel kiln and the periodic kiln. The downdraft periodic kiln is a permanent brick structure that has a number of fireholes where fuel is fired into the furnace. The hot gases from the fuel are drawn up over the bricks, down through them by underground flues, and out of the oven to the chimney. Although fuel efficiency is not as high as that of a tunnel kiln because of lower heat recovery, the uniform temperature distribution through the kiln leads to a good quality product. In most tunnel kilns, cars carrying about 1200 bricks each travel on rails through the kiln at the rate of one 6-foot car per hour. The fire zone is located near the middle of the kiln and remains stationary.

In all kilns, firing takes place in six steps: evaporation of free water, dehydration, oxidation, vitrification, flashing, and cooling. Normally, gas or residual oil is used for heating, but coal may be used. Total heating time varies with the type of product; for example, 9-inch refractory bricks usually require 50 to 100 hours of firing. Maximum temperatures of about 2000°F (1090°C) are used in firing common brick.

8.3.2 Emissions and Controls[1,3]

Particulate matter is the primary emission in the manufacture of bricks. The main source of dust is the materials handling procedure, which includes drying, grinding, screening, and storing the raw material. Combustion products are emitted from the fuel consumed in the curing, drying, and firing portion of the process. Fluorides, largely in gaseous form, are also emitted from brick manufacturing operations. Sulfur dioxide may be emitted from the bricks when temperatures reach 2500°F (1370°C) or greater; however, no data on such emissions are available.[4]

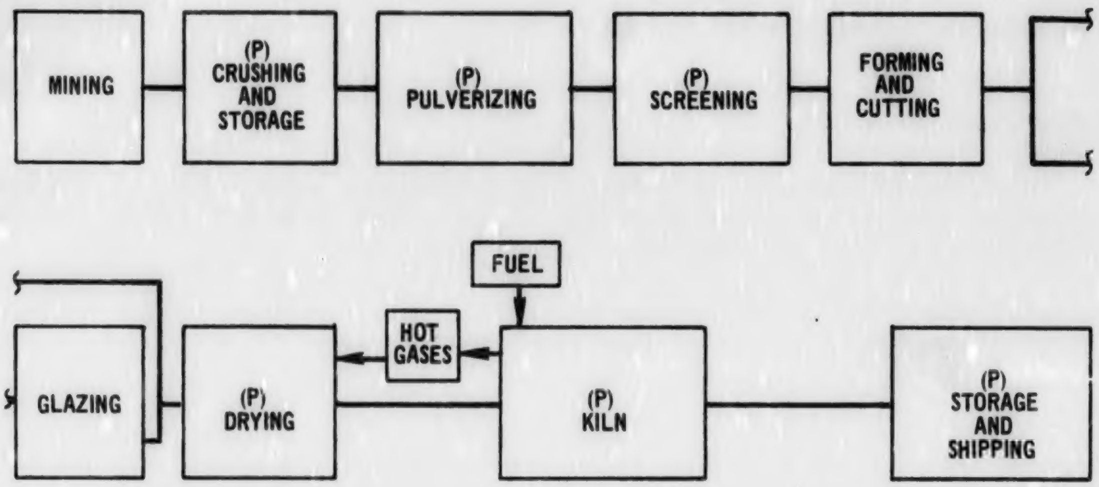
MINING
(P) CRUSHING AND STORAGE
(P) PULVERIZING
(P) SCREENING
FORMING AND CUTTING
FUEL
HOT GASES
GLAZING
(P) DRYING
(P) KILN
(P) STORAGE AND SHIPPING

Figure 8.3-1. Basic flow diagram of brick manufacturing process. "P" denotes a major source of particulate emissions.

A variety of control systems may be used to reduce both particulate and gaseous emissions. Almost any type of particulate control system will reduce emissions from the material handling process, but good plant design and hooding are also required to keep emissions to a minimum.

The emissions of fluorides can be reduced by operating the kiln at temperatures below 2000°F (1090°C) and by choosing clays with low fluoride content. Satisfactory control can be achieved by scrubbing kiln gases with water; wet cyclonic scrubbers are available that can remove fluorides with an efficiency of 95 percent, or higher.

Emission factors for brick manufacturing are presented in Table 8.3-1. Insufficient data are available to present particle size information.

Table 8.3-1. EMISSION FACTORS FOR BRICK MANUFACTURING WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: C

Type of process	Particulates		Sulfur oxides (SO_x)		Carbon monoxide (CO)		Hydrocarbons (HC)		Nitrogen oxides (NO_x)		Fluorides[b] (HF)	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Raw material handling[c]												
Dryers, grinders, etc.	96	48	–	–	–	–	–	–	–	–	–	–
Storage	34	17	–	–	–	–	–	–	–	–	–	–
Curing and firing[d]												
Tunnel kilns												
Gas-fired	0.04	0.02	Neg[e]	Neg	0.04	0.02	0.02	0.01	0.15	0.08	1.0	0.5
Oil-fired	0.6	0.3	4.0S[f]	2.0S	Neg	Neg	0.1	0.05	1.1	0.55	1.0	0.5
Coal-fired	1.0A	0.5A[g]	7.2S	3.6S	1.9	0.95	0.6	0.3	0.9	0.45	1.0	0.5
Periodic kilns												
Gas-fired	0.11	0.05	Neg	Neg	0.11	0.05	0.04	0.02	0.42	0.21	1.0	0.5
Oil-fired	0.9	0.45	5.9S	2.95S	Neg	Neg	0.1	0.05	1.7	0.85	1.0	0.5
Coal-fired	1.6A	0.8A	12.0S	6.0S	3.2	1.6	0.9	0.45	1.4	0.70	1.0	0.5

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[a] One brick weighs about 6.5 pounds (2.95 kg). Emission factors expressed as units per unit weight of brick produced.

[b] Based on data from References 3 and 6 through 10.

[c] Based on data from sections on ceramic clays and cement manufacturing in this publication. Because of process variation, some steps may be omitted. Storage losses apply only to that quantity of material stored.

[d] Based on data from References 1 and 5 and emission factors for fuel combustion.

[e] Negligible.

[f] S is the percent sulfur in the fuel.

[g] A is the percent ash in the coal.

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8.4 CALCIUM CARBIDE MANUFACTURING

8.4.1 Process Description[1,2]

Calcium carbide is manufactured by heating a mixture of quicklime (CaO) and carbon in an electric-arc furnace, where the lime is reduced by the coke to calcium carbide and carbon monoxide. Metallurgical coke, petroleum coke, or anthracite coal is used as the source of carbon. About 1900 pounds (860 kg) of lime and 1300 pounds (600 kg) of coke yield 1 ton (1 MT) of calcium carbide. There are two basic types of carbide furnaces: (1) the open furnace, in which the carbon monoxide burns to carbon dioxide when it comes in contact with air above the charge; and (2) the closed furnace, in which the gas is collected from the furnace. The molten calcium carbide from the furnace is poured into chill cars or bucket conveyors and allowed to solidify. The finished calcium carbide is dumped into a jaw crusher and then into a cone crusher to form a product of the desired size

8.4.2 Emissions and Controls

Particulates, acetylene, sulfur compounds, and some carbon monoxide are emitted from the calcium carbide plants. Table 8.4-1 contains emission factors based on one plant in which some particulate matter escapes from the hoods over each furnace and the remainder passes through wet-impingement-type scrubbers before being vented to the atmosphere through a stack. The coke dryers and the furnace-room vents are also sources of emissions.

Table 8.4-1. EMISSION FACTORS FOR CALCIUM CARBIDE PLANTS[a]
EMISSION FACTOR RATING: C

Type of source	Particulates		Sulfur oxides		Acetylene	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Electric furnace						
Hoods	18	9	–	–	–	–
Main stack	20	10	3	1.5	–	–
Coke dryer	2	1	3	1.5	–	–
Furnace room vents	26	13	–	–	18	9

[a] Reference 3. Emission factors expressed as units per unit weight of calcium carbide produced.

References for Section 8.4

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8.5 CASTABLE REFRACTORIES

8.5.1 Process Description[1-3]

Castable or fused-cast refractories are manufactured by carefully blending such components as alumina, zirconia, silica, chrome, and magnesia; melting the mixture in an electric-arc furnace at temperatures of 3200 to 4500°F (1760 to 2480°C); pouring it into molds; and slowly cooling it to the solid state. Fused refractories are less porous and more dense than kiln-fired refractories.

8.5.2 Emissions and Controls[1]

Particulate emissions occur during the drying, crushing, handling, and blending of the components; during the actual melting process; and in the molding phase. Fluorides, largely in the gaseous form, may also be emitted during the melting operations.

The general types of particulate controls may be used on the materials handling aspects of refractory manufacturing. Emissions from the electric-arc furnace, however, are largely condensed fumes and consist of very fine particles. Fluoride emissions can be effectively controlled with a scrubber. Emission factors for castable refractories manufacturing are presented in Table 8.5-1.

Table 8.5-1. PARTICULATE EMISSION FACTORS FOR CASTABLE REFRACTORIES MANUFACTURING[a]
EMISSION FACTOR RATING: C

Type of process	Type of control	Uncontrolled		Controlled	
		lb/ton	kg/MT	lb/ton	kg/MT
Raw material dryer[b]	Baghouse	30	15	0.3	0.15
Raw material crushing and processing[c]	Scrubber			7	3.5
	Cyclone	120	60	45	22.5
Electric-arc melting[d]	Baghouse	50	25	0.8	0.4
	Scrubber			10	5
Curing oven[e]	–	0.2	0.1	–	–
Molding and shakeout[b]	Baghouse	25	12.5	0.3	0.15

[a] Fluoride emissions from the melt average about 1.3 pounds of HF per ton of melt (0.65 kg HF/MT melt). Emission factors expressed as units per unit weight of feed material.

[b] Reference 4.

[c] References 4 and 5.

[d] References 4 through 6.

[e] Reference 5.

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337<

8.6 PORTLAND CEMENT MANUFACTURING

Revised by Dennis H. Ackerson

8.6.1 Process Description[1-3]

Portland cement manufacture accounts for about 98 percent of the cement production in the United States. The more than 30 raw materials used to make cement may be divided into four basic components: lime (calcareous), silica (siliceous), alumina (argillaceous), and iron (ferriferous). Approximately 3200 pounds of dry raw materials are required to produce 1 ton of cement. Approximately 35 percent of the raw material weight is removed as carbon dioxide and water vapor. As shown in Figure 8.6-1, the raw materials undergo separate crushing after the quarrying operation, and, when needed for processing, are proportioned, ground, and blended using either the wet or dry process.

In the dry process, the moisture content of the raw material is reduced to less than 1 percent either before or during the grinding operation. The dried materials are then pulverized into a powder and fed directly into a rotary kiln. Usually, the kiln is a long, horizontal, steel cylinder with a refractory brick lining. The kilns are slightly inclined and rotate about the longitudinal axis. The pulverized raw materials are fed into the upper end and travel slowly to the lower end. The kilns are fired from the lower end so that the hot gases pass upward and through the raw material. Drying, decarbonating, and calcining are accomplished as the material travels through the heated kiln, finally burning to incipient fusion and forming the clinker. The clinker is cooled, mixed with about 5 percent gypsum by weight, and ground to the final product fineness. The cement is then stored for later packaging and shipment.

With the wet process, a slurry is made by adding water to the initial grinding operation. Proportioning may take place before or after the grinding step. After the materials are mixed, the excess water is removed and final adjustments are made to obtain a desired composition. This final homogeneous mixture is fed to the kilns as a slurry of 30 to 40 percent moisture or as a wet filtrate of about 20 percent moisture. The burning, cooling, addition of gypsum, and storage are carried out as in the dry process.

8.6.2 Emissions and Controls[1,2,4]

Particulate matter is the primary emission in the manufacture of portland cement. Emissions also include the normal combustion products of the fuel used to supply heat for the kiln and drying operations, including oxides of nitrogen and small amounts of oxides of sulfur.

Sources of dust at cement plants include: (1) quarrying and crushing, (2) raw material storage, (3) grinding and blending (dry process only), (4) clinker production, (5) finish grinding, and (6) packaging. The largest source of emissions within cement plants is the kiln operation, which may be considered to have three units: the feed system, the fuel-firing system, and the clinker-cooling and handling system. The most desirable method of disposing of the collected dust is injection into the burning zone of the kiln and production of clinkers from the dust. If the alkali content of the raw materials is too high, however, some of the dust is discarded or leached before returning to the kiln. In many instances, the maximum allowable alkali content of 0.6 percent (calculated as sodium oxide) restricts the amount of dust that can be recycled. Additional sources of dust emissions are raw material storage piles, conveyors, storage silos, and loading/unloading facilities.

The complications of kiln burning and the large volumes of materials handled have led to the adoption of many control systems for dust collection. Depending upon the emission, the temperature of the effluents in the

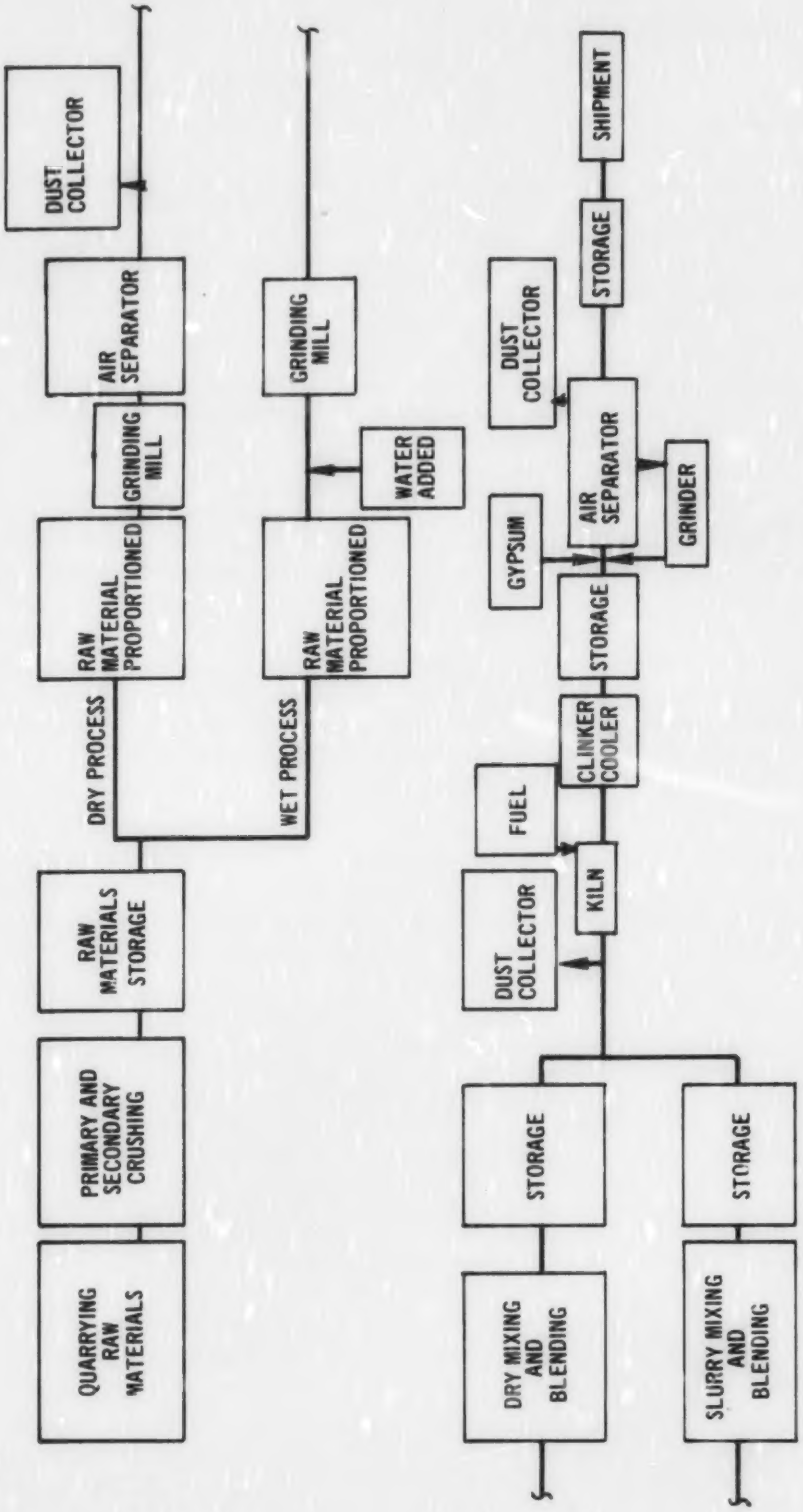
QUARRYING RAW MATERIALS
PRIMARY AND SECONDARY CRUSHING
RAW MATERIALS STORAGE
DRY PROCESS
WET PROCESS
RAW MATERIAL PROPORTIONED
GRINDING MILL
AIR SEPARATOR
DUST COLLECTOR
RAW MATERIAL PROPORTIONED
WATER ADDED
GRINDING MILL
DRY MIXING AND BLENDING
STORAGE
SLURRY MIXING AND BLENDING
STORAGE
DUST COLLECTOR
KILN
FUEL
CLINKER COOLER
STORAGE
GYPSUM
AIR SEPARATOR
GRINDER
DUST COLLECTOR
STORAGE
SHIPMENT

Figure 8.6-1. Basic flow diagram of portland cement manufacturing process.

plant in question, and the particulate emission standards in the community, the cement industry generally uses mechanical collectors, electrical precipitators, fabric filter (baghouse) collectors, or combinations of these devices to control emissions.

Table 8.6-1 summarizes emission factors for cement manufacturing and also includes typical control efficiencies of particulate emissions. Table 8.6-2 indicates the particle size distribution for particulate emissions from kilns and cement plants before control systems are applied.

Table 8.6-1. EMISSION FACTORS FOR CEMENT MANUFACTURING WITHOUT CONTROLS[a,b,c,i]
EMISSION FACTOR RATING: B

	Dry Process		Wet process	
Pollutant	Kilns	Dryers, grinders, etc.	Kilns	Dryers, grinders, etc.
Particulate[d]				
lb/ton	245.0	96.0	228.0	32.0
kg/MT	122.0	48.0	114.0	16.0
Sulfur dioxide[e]				
Mineral source[f]				
lb/ton	10.2	-	10.2	-
kg/MT	5.1	-	5.1	-
Gas combustion				
lb/ton	Neg[g]	-	Neg	-
kg/MT	Neg	-	Neg	-
Oil combustion				
lb/ton	4.2S[h]	-	4.2S	-
kg/MT	2.1S	-	2.1S	-
Coal combustion				
lb/ton	6.8S	-	6.8S	-
kg/MT	3.4S	-	3.4S	-
Nitrogen oxides				
lb/ton	2.6	-	2.6	-
kg/MT	1.3	-	1.3	-

[a] One barrel of cement weighs 376 pounds (171 kg).

[b] These emission factors include emissions from fuel combustion, which should not be calculated separately.

[c] References 1 and 2.

[d] Typical collection efficiencies for kilns, dryers, grinders, etc., are: multicyclones, 80 percent; electrostatic precipitators, 95 percent; electrostatic precipitators with multicyclones, 97.5 percent; and fabric filter units, 99.8 percent.

[e] The sulfur dioxide factors presented take into account the reactions with the alkaline dusts when no baghouses are used. With baghouses, approximately 50 percent more SO_2 is removed because of reactions with the alkaline particulate filter cake. Also note that the total SO_2 from the kiln is determined by summing emission contributions from the mineral source and the appropriate fuel.

[f] These emissions are the result of sulfur being present in the raw materials and are thus dependent upon source of the raw materials used. The 10.2 lb/ton (5.1 kg/MT) factors account for part of the available sulfur remaining behind in the product because of its alkaline nature and affinity for SO_2.

[g] Negligible.

[h] S is the percent sulfur in fuel.

[i] Emission factors expressed in units of tons of cement produced.

Table 8.6-2. SIZE DISTRIBUTION OF DUST EMITTED FROM KILN OPERATIONS WITHOUT CONTROLS[1,5]

Particle size, μm	Kiln dust finer than corresponding particle size, %
60	93
50	90
40	84
30	74
20	58
10	38
5	23
1	3

Sulfur dioxide may be generated from the sulfur compounds in the ores as well as from combustion of fuel. The sulfur content of both ores and fuels will vary from plant to plant and with geographic location. The alkaline nature of the cement, however, provides for direct absorption of SO_2 into the product. The overall control inherent in the process is approximately 75 percent or greater of the available sulfur in ore and fuel if a baghouse that allows the SO_2 to come in contact with the cement dust is used. Control, of course, will vary according to the alkali and sulfur content of the raw materials and fuel.[6]

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8.7 CERAMIC CLAY MANUFACTURING

8.7.1 Process Description[1]

The manufacture of ceramic clay involves the conditioning of the basic ores by several methods. These include the separation and concentration of the minerals by screening, floating, wet and dry grinding, and blending of the desired ore varieties. The basic raw materials in ceramic clay manufacture are kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) and montmorillonite [$(Mg, Ca)\ O \cdot Al_2O_3 \cdot 5SiO_2 \cdot nH_2O$] clays. These clays are refined by separation and bleaching, blended, kiln-dried, and formed into such items as whiteware, heavy clay products (brick, etc.), various stoneware, and other products such as diatomaceous earth, which is used as a filter aid.

8.7.2 Emissions and Controls[1]

Emissions consist primarily of particulates, but some fluorides and acid gases are also emitted in the drying process. The high temperatures of the firing kilns are also conducive to the fixation of atmospheric nitrogen and the subsequent release of NO, but no published information has been found for gaseous emissions. Particulates are also emitted from the grinding process and from storage of the ground product.

Factors affecting emissions include the amount of material processed, the type of grinding (wet or dry), the temperature of the drying kilns, the gas velocities and flow direction in the kilns, and the amount of fluorine in the ores.

Common control techniques include settling chambers, cyclones, wet scrubbers, electrostatic precipitators, and bag filters. The most effective control is provided by cyclones for the coarser material, followed by wet scrubbers, bag filters, or electrostatic precipitators for dry dust. Emission factors for ceramic clay manufacturing are presented in Table 8.7-1.

Table 8.7-1. PARTICULATE EMISSION FACTORS FOR CERAMIC CLAY MANUFACTURING[a]
EMISSION FACTOR RATING: A

Type of process	Uncontrolled		Cyclone[b]		Multiple-unit cyclone and scrubber[c]	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Drying[d]	70	35	18	9	7	3.5
Grinding[e]	76	38	19	9.5	–	–
Storage[d]	34	17	8	4	–	–

[a] Emission factors expressed as units per unit weight of input to process.

[b] Approximate collection efficiency: 75 percent.

[c] Approximate collection efficiency: 90 percent.

[d] References 2 through 5.

[e] Reference 2.

References for Section 8.7-1

1. Air Pollutant Emission Factors. Final Report. Resources Research, Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.

2. Allen, G. L. et al. Control of Metallurgical and Mineral Dusts and Fumes in Los Angeles County. Department of Interior, Bureau of Mines. Washington, D.C. Information Circular Number 7627. April 1952.

3. Private Communication between Resources Research, Incorporated, Reston, Virginia, and the State of New Jersey Air Pollution Control Program, Trenton, New Jersey. July 20, 1969.

4. Henn, J. J. et al. Methods for Producing Alumina from Clay: An Evaluation of Two Lime Sinter Processes. Department of Interior, Bureau of Mines. Washington, D.C. Report of Investigations Number 7299. September 1969.

5. Peters, F. A. et al. Methods for Producing Alumina from Clay: An Evaluation of the Lime-Soda Sinter Process. Department of Interior, Bureau of Mines. Washington, D.C. Report of Investigation Number 6927. 1967.

8.8 CLAY AND FLY-ASH SINTERING

8.8.1 Process Description[1]

Although the processes for sintering fly ash and clay are similar, there are some distinctions that justify a separate discussion of each process. Fly-ash sintering plants are generally located near the source, with the fly ash delivered to a storage silo at the plant. The dry fly ash is moistened with a water solution of lignin and agglomerated into pellets or balls. This material goes to a traveling-grate sintering machine where direct contact with hot combustion gases sinters the individual particles of the pellet and completely burns off the residual carbon in the fly ash. The product is then crushed, screened, graded, and stored in yard piles.

Clay sintering involves the driving off of entrained volatile matter. It is desirable that the clay contain a sufficient amount of volatile matter so that the resultant aggregate will not be too heavy. It is thus sometimes necessary to mix the clay with finely pulverized coke (up to 10 percent coke by weight).[2,3] In the sintering process the clay is first mixed with pulverized coke, if necessary, and then pelletized. The clay is next sintered in a rotating kiln or on a traveling grate. The sintered pellets are then crushed, screened, and stored, in a procedure similar to that for fly ash pellets.

8.8.2 Emissions and Controls[1]

In fly-ash sintering, improper handling of the fly ash creates a dust problem. Adequate design features, including fly-ash wetting systems and particulate collection systems on all transfer points and on crushing and screening operations, would greatly reduce emissions. Normally, fabric filters are used to control emissions from the storage silo, and emissions are low. The absence of this dust collection system, however, would create a major emission problem. Moisture is added at the point of discharge from the silo to the agglomerator, and very few emissions occur there. Normally, there are few emissions from the sintering machine, but if the grate is not properly maintained, a dust problem is created. The consequent crushing, screening, handling, and storage of the sintered product also create dust problems.

In clay sintering, the addition of pulverized coke presents an emission problem because the sintering of coke-impregnated dry pellets produces more particulate emissions than the sintering of natural clay. The crushing, screening, handling, and storage of the sintered clay pellets creates dust problems similar to those encountered in fly-ash sintering. Emission factors for both clay and fly-ash sintering are shown in Table 8.8-1.

Table 8.8-1. PARTICULATE EMISSION FACTORS FOR SINTERING OPERATIONS[a]
EMISSION FACTOR RATING: C

Type of material	Sintering operation[b]		Crushing, screening, and yard storage[b,c]	
	lb/ton	kg/MT	lb/ton	kg/MT
Fly ash[d]	110	55	e	e
Clay mixed with coke[f,g]	40	20	15	7.5
Natural clay[h,i]	12	6	12	6

[a] Emission factors expressed as units per unit weight of finished product.

[b] Cyclones would reduce this emission by about 80 percent.
Scrubbers would reduce this emission by about 90 percent.

[c] Based on data in section on stone quarrying and processing.

[d] Reference 1.

[e] Included in sintering losses.

[f] 90 percent clay, 10 percent pulverized coke; traveling-grate, single-pass, up-draft sintering machine.

[g] References 3 through 5.

[h] Rotary dryer sinterer.

[i] Reference 2.

References for Section 8.8

1. Air Pollutant Emission Factors. Final Report. Resources Research, Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.

2. Communication between Resources Research, Incorporated, Reston, Virginia, and a clay sintering firm. October 2, 1969.

3. Communication between Resources Research, Incorporated, Reston, Virginia, and an anonymous Air Pollution Control Agency. October 16, 1969.

4. Henn, J. J. et al. Methods for Producing Alumina from Clay: An Evaluation of Two Lime Sinter Processes. Department of the Interior, Bureau of Mines. Washington, D.C. Report of Investigation Number 7299. September 1969.

5. Peters, F. A. et al. Methods for Producing Alumina from Clay: An Evaluation of the Lime-Soda Sinter Process. Department of the Interior, Bureau of Mines. Washington, D.C. Report of Investigation Number 6927. 1967.

8.9 COAL CLEANING

8.9.1 Process Description[1]

Coal cleaning is the process by which undesirable materials are removed from bituminous and anthracite coal and lignite. The coal is screened, classified, washed, and dried at coal preparation plants. The major sources of air pollution from these plants are the thermal dryers. Seven types of thermal dryers are presently used: rotary, screen, cascade, continuous carrier, flash or suspension, multilouver, and fluidized bed. The three major types, however, are the flash, multilouver, and fluidized bed.

In the flash dryer, coal is fed into a stream of hot gases where instantaneous drying occurs. The dried coal and wet gases are drawn up a drying column and into the cyclone for separation. In the multilouver dryer, hot gases are passed through falling curtains of coal. The coal is raised by flights of a specially designed conveyor. In the fluidized bed the coal is suspended and dried above a perforated plate by rising hot gases.

8.9.2 Emissions and Controls[1]

Particulates in the form of coal dust constitute the major air pollution problem from coal cleaning plants. The crushing, screening, or sizing of coal are minor sources of dust emissions; the major sources are the thermal dryers. The range of concentration, quantity, and particle size of emissions depends upon the type of collection equipment used to reduce particulate emissions from the dryer stack. Emission factors for coal-cleaning plants are shown in Table 8.9-1. Footnote b of the table lists various types of control equipment and their possible efficiencies.

Table 8.9-1. PARTICULATE EMISSION FACTORS FOR THERMAL COAL DRYERS[a]
EMISSION FACTOR RATING: B

Type of dryer	Uncontrolled emissions[b]	
	lb/ton	kg/MT
Fluidized bed[c]	20	10
Flash[c]	16	8
Multilouvered[d]	25	12.5

[a] Emission factors expressed as units per unit weight of coal dried.

[b] Typical collection efficiencies are: cyclone collectors (product recovery), 70 percent; multiple cyclones (product recovery), 85 percent; water sprays following cyclones, 95 percent; and wet scrubber following cyclones, 99 to 99.9 percent.

[c] References 2 and 3.

[d] Reference 4.

References for Section 8.9

1. Air Pollutant Emission Factors. Final Report. Resources Research, Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.

2. Unpublished stack test results on thermal coal dryers. Pennsylvania Department of Health, Bureau of Air Pollution Control. Harrisburg, Pa.

3. Amherst's Answer to Air Pollution Laws. Coal Mining and Processing. p. 26-29, February 1970.

4. Jones, D. W. Dust Collection at Moss. No. 3. Mining Congress Journal. *55*(7):53-56, July 1969.

8.10 CONCRETE BATCHING

8.10.1 Process Description[1-3]

Concrete batching involves the proportioning of sand, gravel, and cement by means of weigh hoppers and conveyors into a mixing receiver such as a transit mix truck. The required amount of water is also discharged into the receiver along with the dry materials. In some cases, the concrete is prepared for on-site building construction work or for the manufacture of concrete products such as pipes and prefabricated construction parts.

8.10.2 Emissions and Controls[1]

Particulate emissions consist primarily of cement dust, but some sand and aggregate gravel dust emissions do occur during batching operations. There is also a potential for dust emissions during the unloading and conveying of concrete and aggregates at these plants and during the loading of dry-batched concrete mix. Another source of dust emissions is the traffic of heavy equipment over unpaved or dusty surfaces in and around the concrete batching plant.

Control techniques include the enclosure of dumping and loading areas, the enclosure of conveyors and elevators, filters on storage bin vents, and the use of water sprays. Table 8.10-1 presents emission factors for concrete batch plants.

Table 8.10-1. PARTICULATE EMISSION FACTORS FOR CONCRETE BATCHING[a]
EMISSION FACTOR RATING: C

Concrete batching[b]	Emission	
	lb/yd^3 of concrete	kg/m^3 of concrete
Uncontrolled	0.2	0.12
Good control	0.02	0.012

[a] One cubic yard of concrete weighs 4000 pounds (1 m^3 = 2400 kg). The cement content varies with the type of concrete mixed, but 735 pounds of cement per yard (436 kg/m^3) may be used as a typical value.

[b] Reference 4.

References for Section 8.10

1. Air Pollutant Emission Factors. Final Report. Resources Research Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.

2. Vincent, E. J. and J. L. McGinnity. Concrete Batching Plants. In: Air Pollution Engineering Manual. Danielson, J. A. (ed.). U.S. DHEW, PHS, National Center for Air Pollution Control. Cincinnati, Ohio. PHS Publication Number 999-AP-40. 1967. p. 334-335.

3. Communication between Resources Research, Incorporated, Reston, Virginia, and the National Ready-Mix Concrete Association. September 1969.

4. Allen, G. L. et al. Control of Metallurgical and Mineral Dusts and Fumes in Los Angeles County. Department of the Interior, Bureau of Mines. Washington, D.C. Information Circular Number 7627. April 1952.

8.11 FIBER GLASS MANUFACTURING

Revised by James H. Southerland

8.11.1 Process Description

Glass fiber products are manufactured by melting various raw materials to form glass (predominantly borosilicate), drawing the molten glass into fibers, and coating the fibers with an organic material. The two basic types of fiber glass products, textile and wool, are manufactured by different processes. Typical flow diagrams are shown in Figures 8.11-1 and 8.11-2.

8.11.1.1 Textile Products–In the manufacture of textiles, the glass is normally produced in the form of marbles after refining at about 2800°F (1540°C) in a regenerative, recuperative, or electric furnace. The marble-forming stage can be omitted with the molten glass passing directly to orifices to be formed or drawn into fiber filaments. The fiber filaments are collected on spools as continuous fibers and staple yarns, or in the form of a fiber glass mat on a flat, moving surface. An integral part of the textile process is treatment with organic binder materials followed by a curing step.

8.11.1.2 Wool Products–In the manufacture of wool products, which are generally used in the construction industry as insulation, ceiling panels, etc., the molten glass is most frequently fed directly into the forming line without going through a marble stage. Fiber formation is accomplished by air blowing, steam blowing, flame blowing, or centrifuge forming. The organic binder is sprayed onto the hot fibers as they fall from the forming device. The fibers are collected on a moving, flat surface and transported through a curing oven at a temperature of 400° to 600°F (200° to 315°C) where the binder sets. Depending upon the product, the wool may also be compressed as a part of this operation.

8.11.2 Emissions and Controls[1]

The major emissions from the fiber glass manufacturing processes are particulates from the glass-melting furnace, the forming line, the curing oven, and the product cooling line. In addition, gaseous organic emissions occur from the forming line and curing oven. Particulate emissions from the glass-melting furnace are affected by basic furnace design, type of fuel (oil, gas, or electricity), raw material size and composition, and type and volume of the furnace heat-recovery system. Organic and particulate emissions from the forming line are most affected by the composition and quality of the binder and by the spraying techniques used to coat the fibers; very fine spray and volatile binders increase emissions. Emissions from the curing ovens are affected by oven temperature and binder composition, but direct-fired afterburners with heat exchangers may be used to control these emissions. Emission factors for fiber glass manufacturing are summarized in Table 8.11-1.

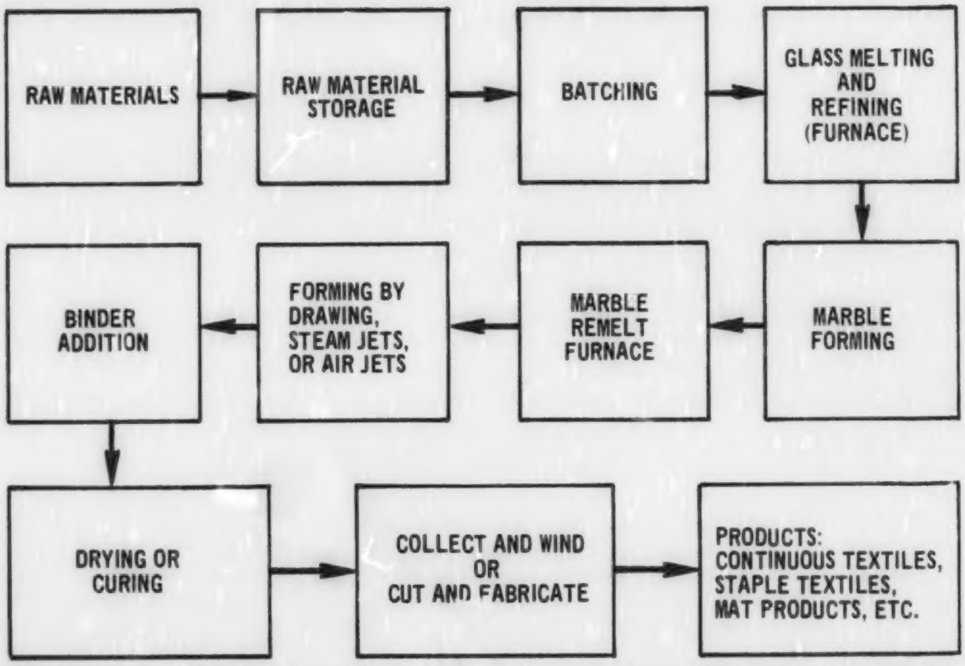
RAW MATERIALS
RAW MATERIAL STORAGE
BATCHING
GLASS MELTING AND REFINING (FURNACE)
MARBLE FORMING
MARBLE REMELT FURNACE
FORMING BY DRAWING, STEAM JETS, OR AIR JETS
BINDER ADDITION
DRYING OR CURING
COLLECT AND WIND OR CUT AND FABRICATE
PRODUCTS: CONTINUOUS TEXTILES, STAPLE TEXTILES, MAT PRODUCTS, ETC.

Figure 8.11-1. Typical flow diagram of textile-type glass fiber production process.

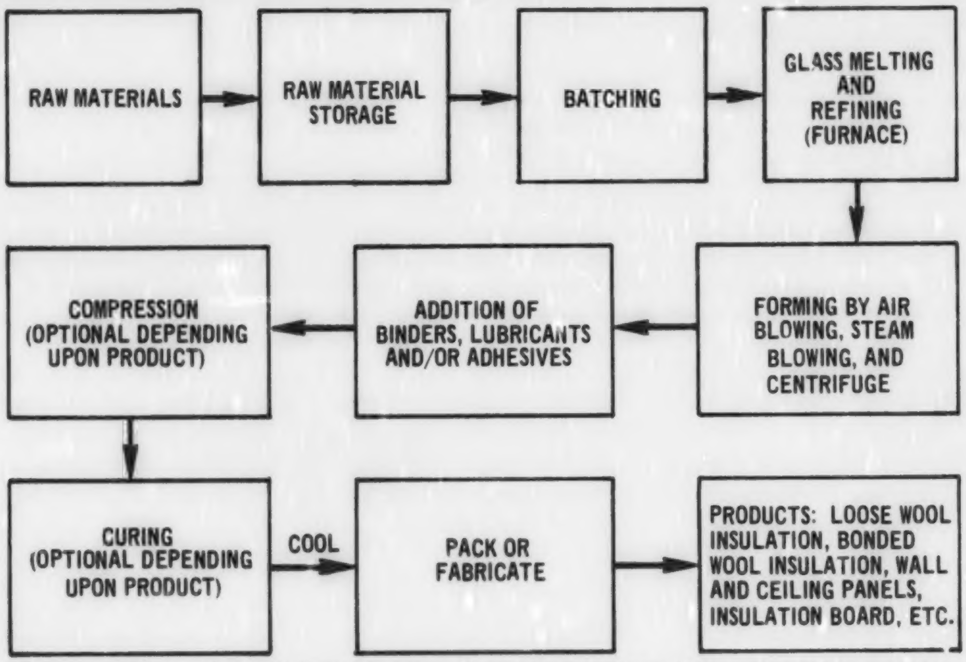
RAW MATERIALS
RAW MATERIAL STORAGE
BATCHING
GLASS MELTING AND REFINING (FURNACE)
FORMING BY AIR BLOWING, STEAM BLOWING, AND CENTRIFUGE
ADDITION OF BINDERS, LUBRICANTS AND/OR ADHESIVES
COMPRESSION (OPTIONAL DEPENDING UPON PRODUCT)
CURING (OPTIONAL DEPENDING UPON PRODUCT)
COOL
PACK OR FABRICATE
PRODUCTS: LOOSE WOOL INSULATION, BONDED WOOL INSULATION, WALL AND CEILING PANELS, INSULATION BOARD, ETC.

Figure 8.11-2. Typical flow diagram of wool-type glass fiber production process.

Table 8.11-1. EMISSION FACTORS FOR FIBER GLASS MANUFACTURING WITHOUT CONTROLS[a,b]
EMISSION FACTOR RATING: A

Type of process	Particulate		Sulfur oxides (SO_2)		Carbon monoxide		Nitrogen oxides (NO_2)		Fluorides	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Textile products										
Glass furnace[c]										
Regenerative	16.4	8.2	29.6	14.8	1.1	0.6	9.2	4.6	3.8	1.9
Recuperative	27.8	13.9	2.7	1.4	0.9	0.5	29.2	14.6	12.5	6.3
Electric	ND[d]	–	–	–	–	–	–	–	–	–
Forming	1.6	0.8	–	–	–	–	–	–	–	–
Curing oven	1.2	0.6	–	–	1.5	0.8	2.6	1.3	–	–
Wool products[e]										
Glass furnace[c]										
Regenerative	21.5	10.8	10.0	5.0	0.25	0.13	5.0	2.5	0.12	0.06
Recuperative	28.3	14.2	9.5	4.8	0.25	0.13	1.70	0.9	0.11	0.06
Electric	0.6	0.3	0.04	0.02	0.05	0.03	0.27	0.14	0.02	0.01
Forming	57.6	28.8	–	–	–	–	–	–	–	–
Curing oven	3.5	1.8	ND	–	1.7	0.9	1.1	0.6	–	–
Cooling	1.3	0.7	–	–	0.2	0.1	0.2	0.1	–	–

[a] Emission factors expressed as units per unit weight of material processed.

[b] Reference 3.

[c] Only one process is generally used at any one plant.

[d] No data available.

[e] In addition, 0.09 lb/ton (0.05 kg/MT) phenol and 3.3 lb/ton (1.7 mg/MT) aldehyde are released from the wool curing and cooling operations.

References for Section 8.11

1. Air Pollutant Emission Factors. Final Report. Resources Research, Inc., Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.

2. Kirk-Othmer. Encyclopedia of Chemical Technology, Vol. X. 2nd Ed. New York, Interscience (John Wiley and Sons, Inc.). 1966. p. 564-566.

3. Private correspondence from S. H. Thomas, Owens-Corning Fiberglas Corp., Toledo, Ohio including intra-company correspondence from R. J. Powels. Subject: Air Pollutant Emission Factors. April 26, 1972.

8.12 FRIT MANUFACTURING

8.12.1 Process Description[1,2]

Frit is used in enameling iron and steel and in glazing porcelain and pottery. In a typical plant, the raw materials consist of a combination of materials such as borax, feldspar, sodium fluoride or fluorspar, soda ash, zinc oxide, litharge, silica, boric acid, and zircon. Frit is prepared by fusing these various minerals in a smelter, and the molten material is then quenched with air or water. This quenching operation causes the melt to solidify rapidly and shatter into numerous small glass particles, called frit. After a drying process, the frit is finely ground in a ball mill where other materials are added.

8.12.2 Emissions and Controls[2]

Significant dust and fume emissions are created by the frit-smelting operation. These emissions consist primarily of condensed metallic oxide fumes that have volatilized from the molten charge. They also contain mineral dust carryover and sometimes hydrogen fluoride. Emissions can be reduced by not rotating the smelter too rapidly (to prevent excessive dust carry-over) and by not heating the batch too rapidly or too long (to prevent volatilizing the more fusible elements).

The two most feasible control devices for frit smelters are baghouses and venturi water scrubbers. Emission factors for frit smelters are shown in Table 8.12-1. Collection efficiencies obtainable for venturi scrubbers are also shown in the table.

Table 8.12-1. EMISSION FACTORS FOR FRIT SMELTERS WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: C

Type of furnace	Particulates[b]		Fluorides[b]	
	lb/ton	kg/MT	lb/ton	kg/MT
Rotary	16	8	5	2.5

[a] Reference 2. Emission factors expressed as units per unit weight of charge.

[b] A venturi scrubber with a 21-inch (535-mm) water-gauge pressure drop can reduce particulate emissions by 67 percent and fluorides by 94 percent.

References for Section 8.12

1. Duprey, R. L. Compilation of Air Pollutant Emission Factors. U.S. DHEW, PHS, National Center for Air Pollution Control. Durham, N.C. PHS Publication Number 999-AP-42. 1968. p. 37-38.

2. Spinks, J. L. Frit Smelters. In: Air Pollution Engineering Manual. Danielson, J. A. (ed.), U.S. DHEW, PHS, National Center for Air Pollution Control. Cincinnati, Ohio. PHS Publication Number 999-AP-40. 1967. p. 738-744.

8.13 GLASS MANUFACTURING

8.13.1 Process Description[1,2]

Nearly all glass produced commercially is one of five basic types: soda-lime, lead, fused silica, borosilicate, and 96 percent silica. Of these, the modern soda-lime glass constitutes 90 percent of the total glass produced and will thus be the only type discussed in this section. Soda-lime glass is produced on a massive scale in large, direct-fired, continuous-melting furnaces in which the blended raw materials are melted at 2700°F (1480°C) to form glass.

8.13.2 Emissions and Controls[1,2]

Emissions from the glass-melting operation consist primarily of particulates and fluorides, if fluoride-containing fluxes are used in the process. Because the dust emissions contain particles that are only a few microns in diameter, cyclones and centrifugal scrubbers are not as effective as baghouses or filters in collecting particulate matter. Table 8.13-1 summarizes the emission factors for glass melting.

Table 8.13-1. EMISSION FACTORS FOR GLASS MELTING
EMISSION FACTOR RATING: D

Type of glass	Particulates[a]		Fluorides[b]	
	lb/ton	kg/MT	lb/ton	kg/MT
Soda-lime	2	1	4F[c]	2F[c]

[a] Reference 3. Emission factors expressed as units per unit weight of glass produced.
[b] Reference 4.
[c] F equals weight percent of fluoride in input to furnace; e.g., if fluoride content is 5 percent, the emission factor would be 4F or 20 (2F or 10).

References for Section 8.13

1. Netzley, A. B. and J. L. McGinnity. Glass Manufacture. In: Air Pollution Engineering Manual. Danielson, J.A. (ed.). U.S. DHEW, PHS, National Center for Air Pollution Control. Cincinnati, Ohio. PHS Publication Number 999-AP-40. 1967. p. 720-730.

2. Duprey, R. L. Compilation of Air Pollutant Emission Factors. U.S. DHEW, PHS, National Center for Air Pollution Control. Durham, N.C. PHS Publication Number 999-AP-42. 1968. p. 38.

3. Technical Progress Report: Control of Stationary Sources. Los Angeles County Air Pollution Control District. *1*: April 1960.

4. Semrau, K. T. Emissions of Fluorides from Industrial Processes: A Review. J. Air Pol. Control Assoc. *7(2)*:92-108, August 1957.

8.14 GYPSUM MANUFACTURING

8.14.1 Process Description[1]

Gypsum, or hydrated calcium sulfate, is a naturally occurring mineral that is an important building material. When heated gypsum loses its water of hydration, it becomes plaster of paris, or when blended with fillers it serves as wall plaster. In both cases the material hardens as water reacts with it to form the solid crystalline hydrate.[2,3]

The usual method of calcination of gypsum consists of grinding the mineral and placing it in large, externally heated calciners. Complete calcination of 1 ton (0.907 MT) of plaster takes about 3 hours and requires about 1.0 million Btu (0.25 million kcal).[4,5]

8.14.2 Emissions[1]

The process of calcining gypsum appears to be devoid of any air pollutants because it involves simply the relatively low-temperature removal of the water of hydration. However, the gases created by the release of the water of crystalization carry gypsum rock dust and partially calcined gypsum dust into the atmosphere.[6] In addition, dust emissions occur from the grinding of the gypsum before calcining and from the mixing of the calcined gypsum with filler. Table 8.14-1 presents emission factors for gypsum processing.

Table 8.14-1. PARTICULATE EMISSION FACTORS FOR GYPSUM PROCESSING[a]
EMISSION FACTOR RATING: C

Type of process	Uncontrolled emissions		With fabric filter		With cyclone and electrostatic precipitator	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Raw-material dryer (if used)	40	20	0.2	0.1	0.4	0.2
Primary grinder	1	0.5	0.001	0.0005	–	–
Calciner	90	45	0.1	0.05	–	–
Conveying	0.7	0.35	0.001	0.0005	–	–

[a] Reference 7. Emission factors expressed as units per unit weight of process throughput.

References for Section 8.14

1. Air Pollutant Emission Factors. Final Report. Resources Research Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.

2. Shreve, R. N. Chemical Process Industries, 3rd Ed. New York, McGraw-Hill Book Company. 1967. p. 180-182.

3. Havinghorst, R. A Quick Look at Gypsum Manufacture. Chem. Eng. *72*:52-54, January 4, 1965.

4. Work, L. T. and A. L. Stern. Size Reduction and Size Enlargement. In: Chemical Engineers Handbook, 4th Ed. New York, McGraw-Hill Book Company. 1963. p. 51.

5. Private communication on emissions from gypsum plants between M. M. Hambuik and the National Gypsum Association, Chicago, Illinois. January 1970.

6. Culhane, F. R. Chem. Eng. Progr. *64*:72, January 1, 1968.

7. Communication between Resources Research, Incorporated, Reston, Virginia, and the Maryland State Department of Health, Baltimore, Maryland. November 1969.

8.15 LIME MANUFACTURING

by Tom Lahre

8.15.1 General[1-4]

Lime is the high-temperature product of the calcination of limestone. There are two kinds of lime: high-calcium lime (CaO) and dolomitic lime ($CaO \cdot MgO$). Lime is manufactured in various kinds of kilns by one of the following reactions:

$$CaCO_3 + \text{heat} \rightarrow CO_2 + CaO \text{ (high calcium lime)}$$

$$CaCO_3 \,.\, MgCO_3 + \text{heat} \rightarrow CO_2 + CaO \,.\, MgO \text{ (dolomitic lime)}$$

In some lime plants, the resulting lime is reacted (slaked) with water to form hydrated lime.

The basic processes in the production of lime are (1) quarrying the raw limestone, (2) preparing the limestone for the kilns by crushing and sizing, (3) calcining the limestone, (4) processing the quicklime further by hydrating, and (5) miscellaneous transfer, storage, and handling operations. A generalized material flow diagram for a lime manufacturing plant is given in Figure 8.15-1. Note that some of the operations shown may not be performed in all plants.

The heart of a lime plant is the kiln. The most prevalent type of kiln is the rotary kiln, accounting for about 90 percent of all lime production in the United States. This kiln is a long, cylindrical, slightly inclined, refractory-lined furnace through which the limestone and hot combustion gases pass countercurrently. Coal, oil, and natural gas may all be fired in rotary kilns. Product coolers and kiln-feed preheaters of various types are commonly employed to recover heat from the hot lime product and and hot exhaust gases, respectively.

The next most prevalent type of kiln in the United States is the vertical, or shaft, kiln. This kiln can be described as an upright heavy steel cylinder lined with refractory material. The limestone is charged at the top and calcined as it descends slowly to the bottom of the kiln where it is discharged. A primary advantage of vertical kilns over rotary kilns is the higher average fuel efficiency. The primary disadvantages of vertical kilns are their relatively low production rates and the fact that coal cannot be used without degrading the quality of the lime produced. Although still prevalent in Europe, there have been few recent vertical kiln installations in the United States because of the high production requirements of domestic manufacturers.

Other, much less common, kiln types include rotary hearth and fluidized-bed kilns. The rotary hearth kiln, or "calcimatic" kiln, is a circular-shaped kiln with a slowly revolving donut-shaped hearth. In fluidized-bed kilns, finely divided limestone is brought into direct contact with hot combustion air in a turbulent zone, usually above a perforated grate. Dust collection equipment must be installed on fluidized-bed kilns for process economics because of the high lime carryover into the exhaust gases. Both kiln types can achieve high production rates, but neither can operate with coal.

About 10 percent of all lime produced is converted to hydrated (slaked) lime. There are two kinds of hydrators: atmospheric and pressure. Atmospheric hydrators, the most prevalent kind, are used to produce high calcium and normal dolomitic hydrates. Pressure hydrators, on the other hand, are only employed when a completely hydrated dolomitic lime is needed. Atmospheric hydrators operate continuously, whereas pressure hydrators operate in a batch mode. Generally, water sprays or wet scrubbers are employed as an integral part of the hydrating process to prevent product losses. Following hydration, the resulting product may be milled and conveyed to air separators for further drying and for removal of the coarse fractions.

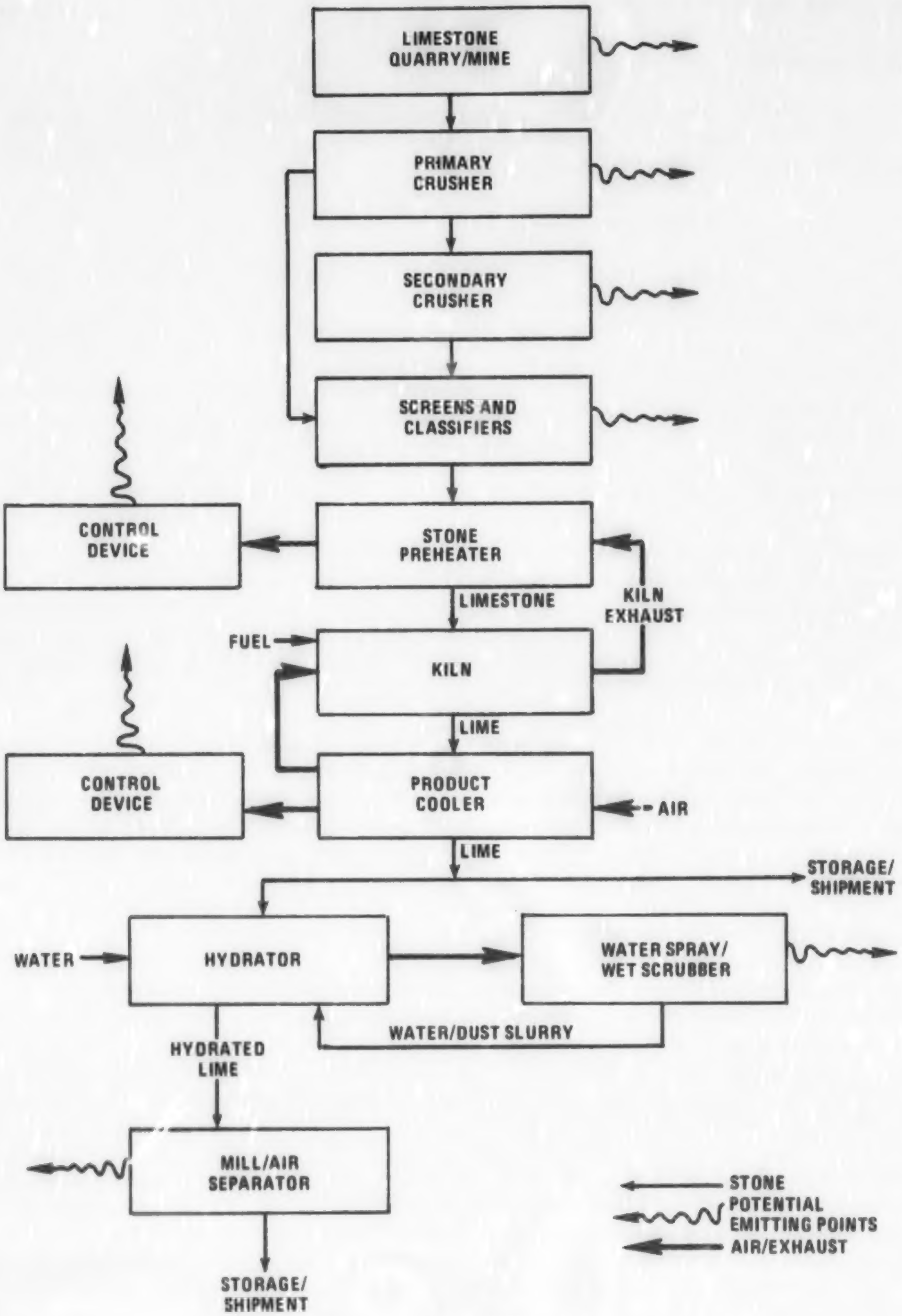
LIMESTONE QUARRY/MINE
PRIMARY CRUSHER
SECONDARY CRUSHER
SCREENS AND CLASSIFIERS
CONTROL DEVICE
STONE PREHEATER
LIMESTONE
KILN EXHAUST
FUEL
KILN
LIME
CONTROL DEVICE
PRODUCT COOLER
AIR
LIME
STORAGE/ SHIPMENT
WATER
HYDRATOR
WATER SPRAY/ WET SCRUBBER
WATER/DUST SLURRY
HYDRATED LIME
MILL/AIR SEPARATOR
STORAGE/ SHIPMENT
STONE
POTENTIAL EMITTING POINTS
AIR/EXHAUST

Figure 8.15-1. Generalized lime manufacturing plant.

In the United States, the major use of lime is in chemical and metallurgical applications. Two of the largest uses in these areas are as steel flux and in alkali production. Other lesser uses include construction, refractory, and agricultural applications.

8.15.2 Emissions and Controls[3-5]

Potential air pollutant emitting points in lime manufacturing plants are shown in Figure 8.15-1. Particulate is the only pollutant of concern from most of the operations; however, gaseous pollutants are also emitted from kilns.

The largest source or particulate is the kiln. Of the various kiln types in use, fluidized-bed kilns have the highest uncontrolled particulate emissions. This is due primarily to the very small feed size combined with the high air flow through these kilns. Fluidized-bed kilns are well controlled for maximum product recovery. The rotary kiln is second to the fluidized-bed kiln in uncontrolled particulate emissions. This is attributed to the small feed size and relatively high air velocities and dust entrainment caused by the rotating chamber. The rotary hearth, or "calcimatic" kiln ranks third in dust production, primarily because of the larger feed size combined with the fact that the limestone remains in a stationary position relative to the hearth during calcination. The vertical kiln has the lowest uncontrolled dust emissions due to the large lump-size feed and the relatively slow air velocities and slow movement of material through the kiln.

Some sort of particulate control is generally employed on most kilns. Rudimentary fallout chambers and cyclone separators are commonly used for control of the larger particles; fabric and gravel bed filters, wet (commonly venturi) scubbers, and electrostatic precipitators are employed for secondary control. Table 8.15-1 yields approximate efficiencies of each type of control on the various types of kilns.

Nitrogen oxides, carbon monoxide, and sulfur oxides are all produced in kilns, although the latter are the only gaseous pollutant emitted in significant quantities. Not all of the sulfur in the kiln fuel is emitted as sulfur oxides because some fraction reacts with the materials in the kiln. Some sulfur oxide reduction is also effected by the various equipment used for secondary particulate control. Estimates of the quantities of sulfur oxides emitted from kilns, both before and after controls, are presented in Table 8.15-1.

Hydrator emissions are low because water sprays or wet scrubbers are usually installed for economic reasons to prevent product loss in the exhaust gases. Emissions from pressure hydrators may be higher than from the more common atmospheric hydrators because the exhaust gases are released intermittently over short time intervals, making control more difficult.

Product coolers are emission sources only when some of their exhaust gases are not recycled through the kiln for use as combustion air. The trend is away from the venting of product cooler exhaust, however, to maximize fuel use efficiencies. Cyclones, baghouses, and wet scrubbers have been employed on coolers for particulate control.

Other particulate sources in lime plants include primary and secondary crushers, mills, screens, mechanical and pneumatic transfer operations, storage piles, and unpaved roads. If quarrying is a part of the lime plant operation, particulate may also result from drilling and blasting. Emission factors for some of these operations are presented in Sections 8.20 and 11.2.

Emission factors for lime manufacturing are presented in Table 8.15-1.

Table 8.15-1. EMISSION FACTORS FOR LIME MANUFACTURING
EMISSION FACTOR RATING: B

Source	Emissions[a]							
	Particulate		Sulfur dioxide		Nitrogen oxides		Carbon monoxide	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Crushers, screens, conveyors, storage piles, unpaved roads	b	b	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.
Rotary kilns								
Uncontrolled[c]	340	170	d	d	3	1.5	2	1
After settling chamber or large diameter cyclone	200	100	d	d	3	1.5	2	1
After multiple cyclones	85[e]	43[e]	d	d	3	1.5	2	1
After secondary dust collection[f]	1	0.5	g	g	3	1.5	2	1
Vertical kilns								
Uncontrolled	8	4	NA[h]	NA[h]	NA	NA	NA	NA
Calcimatic kilns[i]								
Uncontrolled	50	25	NA	NA	0.2	0.1	NA	NA
After multiple cyclones	6	3	NA	NA	0.2	0.1	NA	NA
After secondary dust collection[j]	NA	NA	NA	NA	0.2	0.1	NA	NA
Fluidized-bed kilns	NA[k]	NA[k]	NA	NA	NA	NA	NA	NA
Product coolers								
Uncontrolled	40[l]	20[l]	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.
Hydrators	0.1[m]	0.05[m]	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.

[a] All emission factors for kilns and coolers are per unit of lime produced. Divide by two to obtain factors per unit of limestone feed to the kiln. Factors for hydrators are per unit of hydrated lime produced. Multiply by 1.25 to obtain factors per unit of lime feed to the hydrator. All emissions data are based on References 4 through 6.

[b] Emission factors for these operations are presented in Sections 8.20 and 11.2.

[c] No particulate control except for settling that may occur in the stack breeching and chimney base.

[d] When low-sulfur (less than 1 percent, by weight) fuels are used, only about 10 percent of the fuel sulfur is emitted as SO_2. When high-sulfur fuels are used, approximately 50 percent of the fuel sulfur is emitted as SO_2.

[e] This factor should be used when coal is fired in the kiln. Limited data suggest that when only natural gas or oil is fired, particulate emissions after multiple cyclones may be as low as 20 to 30 lb/ton (10 to 15 kg/MT).

[f] Fabric or gravel bed filters, electrostatic precipitators, or wet (most commonly venturi) scrubbers. Particulate concentrations as low as 0.2 lb/ton (0.1 kg/MT) have been achieved using these devices.

[g] When scrubbers are used, less than 5 percent of the fuel sulfur will be emitted as SO_2, even with high-sulfur coal. When other secondary collection devices are used, about 20 percent of the fuel sulfur will be emitted as SO_2 with high-sulfur fuels and less than 10 percent with low-sulfur fuels.

[h] Not available.

[i] Calcimatic kilns generally employ stone preheaters. All factors represent emissions after the kiln exhaust passes through a preheater.

[j] Fabric filters and venturi scrubbers have been employed on calcimatic kilns. No data are available on particulate emissions after secondary control.

[k] Fluidized-bed kilns must employ sophisticated dust collection equipment for process economics; hence, particulate emissions will depend on the efficiency of the control equipment installed.

[l] Some or all of the cooler exhaust is typically used in the kiln as combustion air. Emissions will result only from that fraction that is not recycled to the kiln.

[m] This is a typical particulate loading for atmospheric hydrators following water sprays or wet scrubbers. Limited data suggest particulate emissions from pressure hydrators may be approximately 2 lb/ton (1 kg/MT) of hydrate produced, after wet collectors.

References for Section 8.15

1. Lewis, C.J. and B.B. Crocker. The Lime Industry's Problem of Airborne Dust. J. Air Pol. Control Asso. Vol. 19, No. 1. January 1969.

2. Kirk-Othmer Encyclopedia of Chemical Technology. 2nd Ed. Vol 12. New York, John Wiley and Sons. 1967. p. 414-459.

3. Screening Study for Emissions Characterization From Lime Manufacture. Vulcan-Cincinnati. Cincinnati, Ohio. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, N.C. Under Contract No. 68-02-0299. August 1974.

4. Evans, L.B. et al. An Investigation of the Best Systems of Emission Reduction For Rotary Kilns and Lime Hydrators in the Lime Industry. Standards Support and Environmental Impact Statement. Office of Air Quality Planning and Standards. U.S. Environmental Protection Agency. Research Triangle Park, N.C. February 1976.

5. Source Test Data on Lime Plants from Office of Air Quality Planning and Standards. U.S. Environmental Protection Agency. Research Triangle Park, N.C. 1976.

6. Air Pollutant Emission Factors. TRW Systems Group. Reston, Virginia. Prepared for the National Air Pollution Control Administration, U.S. Department of Health, Education, and Welfare. Washington, D.C. under Contract No. CPA 22-69-119. April 1970. P. 2-2 through 2-19.

8.16 MINERAL WOOL MANUFACTURING

8.16.1 Process Description[1,2]

The product mineral wool used to be divided into three categories: slag wool, rock wool, and glass wool. Today, however, straight slag wool and rock wool as such are no longer manufactured. A combination of slag and rock constitutes the charge material that now yields a product classified as a mineral wool, used mainly for thermal and acoustical insulation.

Mineral wool is made primarily in cupola furnaces charged with blast-furnace slag, silica rock, and coke. The charge is heated to a molten state at about 3000°F (1650°C) and then fed to a blow chamber, where steam atomizes the molten rock into globules that develop long fibrous tails as they are drawn to the other end of the chamber. The wool blanket formed is next conveyed to an oven to cure the binding agent and then to a cooler.

8.16.2 Emissions and Controls

The major source of emissions is the cupola or furnace stack. Its discharge consists primarily of condensed fumes that have volatilized from the molten charge and gases such as sulfur oxides and fluorides. Minor sources of particulate emissions include the blowchamber, curing oven, and cooler. Emission factors for various stages of mineral wool processing are shown in Table 8.16-1. The effect of control devices on emissions is shown in footnotes to the table.

Table 8.16-1. EMISSION FACTORS FOR MINERAL WOOL PROCESSING WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: C

Type of process	Particulates		Sulfur oxides	
	lb/ton	kg/MT	lb/ton	kg/MT
Cupola	22	11	0.02	0.01
Reverberatory furnace	5	2.5	Neg[b]	Neg
Blow chamber[c]	17	8.5	Neg	Neg
Curing oven[d]	4	2	Neg	Neg
Cooler	2	1	Neg	Neg

[a] Reference 2. Emission factors expressed as units per unit weight of charge.

[b] Negligible.

[c] A centrifugal water scrubber can reduce particulate emissions by 60 percent.

[d] A direct-flame afterburner can reduce particulate emissions by 50 percent.

References for Section 8.16

1. Duprey, R. L. Compilation of Air Pollutant Emission Factors. U.S. DHEW, PHS, National Center for Air Pollution Control. Durham, N. C. PHS Publication Number 999-AP-42. 1968. p. 39-40.

2. Spinks, J. L. Mineral Wool Furnaces. In: Air Pollution Engineering Manual. Danielson, J. A. (ed.). U.S. DHEW, PHS, National Center for Air Pollution Control. Cincinnati, Ohio. PHS Publication Number 999-AP-40. 1967. p. 343-347.

8.17 PERLITE MANUFACTURING

8.17.1 Process Description[1,2]

Perlite is a glassy volcanic rock consisting of oxides of silicon and aluminum combined as a natural glass by water of hydration. By a process called exfoliation, the material is rapidly heated to release water of hydration and thus to expand the spherules into low-density particles used primarily as aggregate in plaster and concrete. A plant for the expansion of perlite consists of ore unloading and storage facilities, a furnace-feeding device, an expanding furnace, provisions for gas and product cooling, and product-classifying and product-collecting equipment. Vertical furnaces, horizontal stationary furnaces, and horizontal rotary furnaces are used for the exfoliation of perlite, although the vertical types are the most numerous. Cyclone separators are used to collect the product.

8.17.2 Emissions and Controls[2]

A fine dust is emitted from the outlet of the last product collector in a perlite expansion plant. The fineness of the dust varies from one plant to another, depending upon the desired product. In order to achieve complete control of these particulate emissions, a baghouse is needed. Simple cyclones and small multiple cyclones are not adequate for collecting the fine dust from perlite furnaces. Table 8.17-1 summarizes the emissions from perlite manufacturing.

Table 8.17-1. PARTICULATE EMISSION FACTORS FOR PERLITE EXPANSION FURNACES WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: C

Type of furnace	Emissions[b]	
	lb/ton	kg/MT
Vertical	21	10.5

[a] Reference 3. Emission factors expressed as units per unit weight of charge.

[b] Primary cyclones will collect 80 percent of the particulates above 20 micrometers, and baghouses will collect 96 percent of the particles above 20 micrometers.[2]

References for Section 8.17

1. Duprey, R. L. Compilation of Air Pollutant Emission Factors. U.S. DHEW, PHS, National Center for Air Pollution Control. Durham, N.C. PHS Publication Number 999-AP-42. 1968. p. 39.

2. Vincent, E. J. Perlite-Expanding Furnaces. In: Air Pollution Engineering Manual. Danielson, J. A. (ed.). U.S. DHEW, PHS, National Center for Air Pollution Control. Cincinnati, Ohio. PHS Publication Number 999-AP-40. 1967. p. 350-352.

3. Unpublished data on perlite expansion furnace. National Center for Air Pollution Control. Cincinnati, Ohio. July 1967.

8.18 PHOSPHATE ROCK PROCESSING

8.18.1 Process Description[1]

Phosphate rock preparation involves beneficiation to remove impurities, drying to remove moisture, and grinding to improve reactivity. Usually, direct-fired rotary kilns are used to dry phosphate rock. These dryers burn natural gas or fuel oil and are fired counter-currently. The material from the dryers may be ground before storage in large storage silos. Air-swept ball mills are preferred for grinding phosphate rock.

8.18.2 Emissions and Controls[1]

Although there are no significant emissions from phosphate rock beneficiation plants, emissions in the form of fine rock dust may be expected from drying and grinding operations. Phosphate rock dryers are usually equipped with dry cyclones followed by wet scrubbers. Particulate emissions are usually higher when drying pebble rock than when drying concentrate because of the small adherent particles of clay and slime on the rock. Phosphate rock grinders can be a considerable source of particulates. Because of the extremely fine particle size, baghouse collectors are normally used to reduce emissions. Emission factors for phosphate rock processing are presented in Table 8.18-1.

Table 8.18-1. PARTICULATE EMISSION FACTORS FOR PHOSPHATE ROCK PROCESSING WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: C

Type of source	Emissions	
	lb/ton	kg/MT
Drying[b,c]	15	7.5
Grinding[b,d]	20	10
Transfer and storage[d,e]	2	1
Open storage piles[e]	40	20

[a] Emission factors expressed as units per unit weight of phosphate rock.

[b] References 2 and 3.

[c] Dry cyclones followed by wet scrubbers can reduce emissions by 95 to 99 percent.

[d] Dry cyclones followed by fabric filters can reduce emissions by 99.5 to 99.9 percent.

[e] Reference 3.

References for Section 8.18

1. Stern, A. (ed.). In: Air Pollution, Vol. III, 2nd Ed. Sources of Air Pollution and Their Control. New York, Academic Press. 1968. p. 221-222.

2. Unpublished data from phosphate rock preparation plants in Florida. Midwest Research Institute. June 1970.

3. Control Techniques for Fluoride Emissions. Internal document. U.S. Environmental Protection Agency, Office of Air Programs, Durham, N.C. p. 4-46, 4-36, and 4-34.

8.19 SAND AND GRAVEL PROCESSING

By James H. Southerland

8.19.1 Process Description[1]

Deposits of sand and gravel, the consolidated granular materials resulting from the natural disintegration of rock or stone, are found in banks and pits and in subterranean and subaqueous beds.

Depending upon the location of the deposit, the materials are excavated using power shovels, draglines, cableways, suction dredge pumps, or other apparatus; light-charge blasting may be necessary to loosen the deposit. The materials are transported to the processing plant by suction pump, earth mover, barge, truck, or other means. The processing of sand and gravel for a specific market involves the use of different combinations of washers; screens and classifiers, which segregate particle sizes; crushers, which reduce oversize material; and storage and loading facilities.

8.19.2 Emissions[2,3]

Dust emissions occur during conveying, screening, crushing, and storing operations. Because these materials are generally moist when handled, emissions are much lower than in a similar crushed stone operation. Sizeable emissions may also occur as vehicles travel over unpaved roads and paved roads covered by dirt. Although little actual source testing has been done, an estimate has been made for particulate emissions from a plant using crushers:

Particulate emissions: 0.1 lb/ton (0.05 kg/MT) of product.[3]

References for Section 8.19

1. Walker, Stanton. Production of Sand and Gravel. National Sand and Gravel Association. Washington, D.C. Circular Number 57. 1954.

2. Schreibeis, William J. and H. H. Schrenk. Evaluation of Dust and Noise Conditions at Typical Sand and Gravel Plants. Study conducted under the auspices of the Committee on Public Relations, National Sand and Gravel Association, by the Industrial Hygiene Foundation of America, Inc. 1958.

3. Particulate Pollutant System Study, Vol. I, Mass Emissions. Midwest Research Institute, Kansas City, Mo. Prepared for the Environmental Protection Agency, Research Triangle Park, N.C., under Contract Number CPA 22-69-104. May 1971.

8.20 STONE QUARRYING AND PROCESSING

8.20.1 Process Description[1]

Rock and crushed stone products are loosened by drilling and blasting them from their deposit beds and are removed with the use of heavy earth-moving equipment. This mining of rock is done primarily in open pits. The use of pneumatic drilling and cutting, as well as blasting and transferring, causes considerable dust formation. Further processing includes crushing, regrinding, and removal of fines.[2] Dust emissions can occur from all of these operations, as well as from quarrying, transferring, loading, and storage operations. Drying operations, when used, can also be a source of dust emissions.

8.20.2 Emissions[1]

As enumerated above, dust emissions occur from many operations in stone quarrying and processing. Although a big portion of these emissions is heavy particles that settle out within the plant, an attempt has been made to estimate the suspended particulates. These emission factors are shown in Table 8.20-1. Factors affecting emissions include the amount of rock processed; the method of transfer of the rock; the moisture content of the raw material; the degree of enclosure of the transferring, processing, and storage areas; and the degree to which control equipment is used on the processes.

Table 8.20-1. PARTICULATE EMISSION FACTORS FOR ROCK-HANDLING PROCESSES
EMISSION FACTOR RATING: C

Type of process	Uncontrolled total[a]		Settled out in plant, %	Suspended emission	
	lb/ton	kg/MT		lb/ton	kg/MT
Dry crushing operations[b,c]					
Primary crushing	0.5	0.25	80	0.1	0.05
Secondary crushing and screening	1.5	0.75	60	0.6	0.3
Tertiary crushing and screening (if used)	6	3	40	3.6	1.8
Recrushing and screening	5	2.5	50	2.5	1.25
Fines mill	6	3	25	4.5	2.25
Miscellaneous operations[d]					
Screening, conveying, and handling[e]	2	1			
Storage pile losses[f]					

[a] Typical collection efficiencies: cyclone, 70 to 85 percent; fabric filter, 99 percent.

[b] All values are based on raw material entering primary crusher, except those for recrushing and screening, which are based on throughput for that operation.

[c] Reference 3.

[d] Based on units of stored product.

[e] Reference 4.

[f] See section 11.2.3.

References for Section 8.20

1. Air Pollutant Emission Factors. Final Report. Resources Research, Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.

2. Communication between Resources Research, Incorporated, Reston, Virginia, and the National Crushed Stone Association. September 1969.

3. Culver, P. Memorandum to files. U.S. DHEW, PHS, National Air Pollution Control Administration, Division of Abatement, Durham, N.C. January 6, 1968.

4. Unpublished data on storage and handling of rock products. U.S. DHEW, PHS, National Air Pollution Control Administration, Division of Abatement, Durham, N.C. May 1967.

5. Stern, A. (ed.) In: Air Pollution, Vol. III, 2nd Ed. Sources of Air Pollution and Their Control. New York, Academic Press. 1968. p. 123-127.

9. PETROLEUM INDUSTRY

9.1 PETROLEUM REFINING

Revised by William M. Vatavuk

9.1.1 General

Although a modern refinery is a complex system of many processes, the entire operation can be divided into four major steps: separating, converting, treating, and blending. The crude oil is first separated into selected fractions (e.g. gasoline, kerosene, fuel, oil, etc.). Because the relative volumes of each fraction produced by merely separating the crude may not conform to the market demands for each fraction, some of the less valuable products, such as heavy naptha, are converted to products with a greater sale value, such as gasoline. This conversion is accomplished by splitting (cracking), uniting (polymerization), or rearranging (reforming) the original molecules. The final step is the blending of the refined base stocks with each other and with various additives to meet final product specifications. The various unit operations involved at petroleum refineries will be briefly discussed in the following sections. A generalized petroleum refinery flow sheet is shown in Figure 9.1-1.

9.1.2 Crude Oil Distillation[1-6]

Crude oil is a mixture of many different hydrocarbons, some of them combined with small amounts of impurities. Crude oils vary considerably in composition and physical properties, but primarily consist of three families of hydrocarbons: paraffins, saturated hydrocarbons having the empirical formula C_nH_{2n+2}; napthenes, ring-structure saturated hydrocarbons with the formula C_nH_{2n}; and aromatics, characterized by a benzene ring, C_6H_6, in the molecular structure. In addition to carbon and hydrogen, significant amounts of sulfur, oxygen, and nitrogen can be present in crude petroleum.

Separation of these hydrocarbon constituents into their respective fractions is performed by simple distillation in crude topping or skimming units. Crude oil is heated in pipe stills and passed to fractionating towers or columns for vaporization and preparation. Heavy fractions of the crude oil, which do not vaporize in the topping operation, are separated by steam or vacuum distillation. The heavy residuum products are reduced to coke and more valuable volatile products via destructive distillation and coking. Depending on the boiling range of the stock and its stability with respect to heat and product specifications, solvent extraction and/or absorption techniques can also be used. The distillation fractions - "straight run products" - usually include refinery gas, gasoline, kerosene, light fuel oil, diesel oils, gas oil, lube distillate, and heavy bottoms, the amount of each being determined by the type and composition of the crude oil. Some of these products are treated to remove impurities and used as base stocks or sold as finished products; the remainder are used as feedstock for other refinery units.

9.1.2.1 Emissions–The main source of emissions from crude oil preparation processes is the barometric condenser on the vacuum distillation column. This condenser, while maintaining a vacuum on the tower, often allows noncondensable light hydrocarbons and hydrogen sulfide to pass through to the atmosphere. The quantity of these emissions is a function of the unit size, type of feedstock, and the cooling water temperature. Vapor recovery systems reduce these emissions to negligible amounts (see Table 9.1-1).

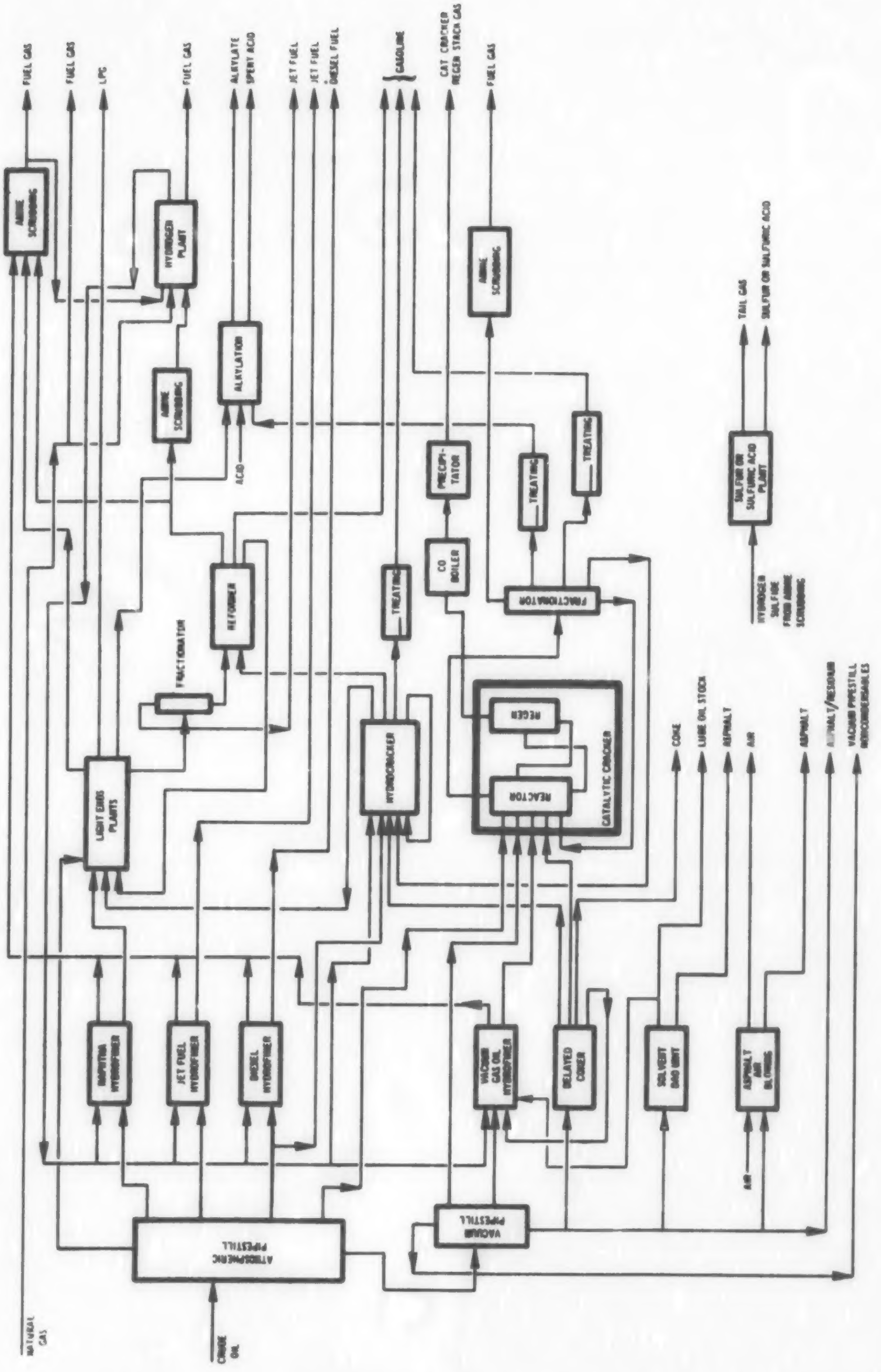
FUEL GAS
FUEL GAS
LPG
FUEL GAS
ALKYLATE
SPENT ACID
JET FUEL
JET FUEL
DIESEL FUEL
GASOLINE
CAT CRACKER REGEN STACK GAS
FUEL GAS
AMINE SCRUBBING
HYDROGEN PLANT
AMINE SCRUBBING
ALKYLATION
ACID
AMINE SCRUBBING
PRECIPITATOR
TREATING
TREATING
TAIL GAS
SULFUR OR SULFURIC ACID
REFORMER
FRACTIONATOR
TREATING
CO BOILER
FRACTIONATOR
SULFUR OR SULFURIC ACID PLANT
HYDROGEN SULFIDE FROM AMINE SCRUBBING
LIGHT ENDS PLANTS
HYDROCRACKER
REGEN
REACTOR
CATALYTIC CRACKER
COKE
LUBE OIL STOCK
ASPHALT
AIR
ASPHALT
ASPHALT/RESIDUUM
VACUUM PIPESTILL NONCONDENSABLES
NAPHTHA HYDROFINER
JET FUEL HYDROFINER
DIESEL HYDROFINER
VACUUM GAS OIL HYDROFINER
DELAYED COKER
SOLVENT DAO UNIT
ASPHALT AIR BLOWING
AIR
ATMOSPHERIC PIPESTILL
VACUUM PIPESTILL
NATURAL GAS
CRUDE OIL

Figure 9.1-1. Basic flow diagram of petroleum refinery.

Table 9.1-1. EMISSION FACTORS FOR PETROLEUM REFINERIES
EMISSION FACTOR RATING: A

Type of process	Particulates	Sulfur oxides (SO_2)	Carbon monoxide	Hydro-carbons	Nitrogen oxides (NO_2)	Alde-hydes	Ammonia
Boilers and process heaters[a]							
lb/10^3 bbl oil burned	840	6,720S[b]	Neg[c]	140	2,900	25	Neg
kg/10^3 liters oil burned	2.4	19.2S	Neg	0.4	8.3	0.071	Neg
lb/10^3 ft^3 gas burned	0.02	2s[d]	Neg	0.03	0.23	0.003	Neg
kg/10^3 m^3 gas burned	0.32	32s	Neg	0.48	3.7	0.048	Neg
Fluid catalytic cracking units[e]							
Uncontrolled							
lb/10^3 bbl fresh feed	242 (93 to 340)[f]	493 (313 to 525)	13,700	220	71.0 (37.1 to 145.0)	19	54
kg/10^3 liters fresh feed	0.695 (0.267 to 0.976)	1.413 (0.898 to 1.505)	39.2	0.630	0.204 (0.107 to 0.416)	0.054	0.155
Electrostatic precipitator and CO boiler							
lb/10^3 bbl fresh feed	44.7 (12.5 to 61.0)	493 (313 to 525)	Neg	220	71.0 (37.1 to 145.0)	19	54
kg/10^3 liters fresh fresh feed	0.128 (0.036 to 0.175)	1.413 (0.898 to 1.505)	Neg	0.630	0.204 (0.107 to 0.416)	0.054	0.155
Moving-bed catalytic cracking units[a]							
lb/10^3 bbl fresh feed	17	60	3,800	87	5	12	6
kg/10^3 liters fresh feed	0.049	0.171	10.8	0.250	0.014	0.034	0.017
Fluid coking units[g]							
Uncontrolled							
lb/10^3 bbl fresh feed	523	NA[h]	Neg	Neg	Neg	Neg	Neg
kg/10^3 liters fresh feed	1.50	NA	Neg	Neg	Neg	Neg	Neg
Electrostatic precipitator							
lb/10^3 bbl fresh feed	6.85	NA	Neg	Neg	Neg	Neg	Neg
kg/10^3 liters fresh feed	0.0196	NA	Neg	Neg	Neg	Neg	Neg

Table 9.1-1. (continued). EMISSION FACTORS PETROLEUM REFINERIES EMISSION FACTOR RATING: A

Type of process	Particulates	Sulfur oxides (SO_2)	Carbon monoxide	Hydrocarbons	Nitrogen oxides (NO_2)	Aldehydes	Ammonia
Compressor internal combustion engines[a]							
lb/10^3 ft^3 gas burned	Neg	2s	Neg	1.2	0.9	0.1	0.2
kg/10^3 m^3 gas burned	Neg	32s	Neg	19.3	14.4	1.61	3.2
Blowdown systems[a]							
Uncontrolled							
lb/10^3 bbl refinery capacity	Neg	Neg	Neg	300	Neg	Neg	Neg
kg/10^3 liters refinery capacity	Neg	Neg	Neg	0.860	Neg	Neg	Neg
Vapor recovery system or flaring							
lb/10^3 bbl refinery capacity	Neg	Neg	Neg	5	Neg	Neg	Neg
kg/10^3 liters refinery capacity	Neg	Neg	Neg	0.014	Neg	Neg	Neg
Process drains, Uncontrolled							
lb/10^3 bbl waste water	Neg	Neg	Neg	210	Neg	Neg	Neg
kg/10^3 liters waste water	Neg	Neg	Neg	0.600	Neg	Neg	Neg
Vapor recovery or separator covers							
lb/10^3 bbl waste water	Neg	Neg	Neg	8	Neg	Neg	Neg
kg/10^3 liters waste water	Neg	Neg	Neg	0.023	Neg	Neg	Neg
Vacuum jets[a]							
Uncontrolled							
lb/10^3 bbl vacuum distillate	Neg	Neg	Neg	130	Neg	Neg	Neg
kg/10^3 liters vacuum distillate	Neg	Neg	Neg	0.370	Neg	Neg	Neg
Fume burner or waste-heat boiler							
lb/10^3 bbl vacuum distillate	Neg	Neg	Neg	Neg	Neg	Neg	Neg

Table 9.1-1. (continued). EM ION FACTORS FOR PETROLEUM REFINERIES
EMISSION FACTOR RATING: A

Type of process	Particulates	Sulfur oxides (SO_2)	Carbon monoxide	Hydro-carbons	Nitrogen oxides (NO_2)	Alde-hydes	Ammonia
$kg/10^3$ liters vacuum distillate	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Cooling towers[a]							
$lb/10^6$ gal cooling water	Neg	Neg	Neg	6	Neg	Neg	Neg
$kg/10^6$ liters cooling water	Neg	Neg	Neg	0.72	Neg	Neg	Neg
Pipeline valves and flanges[a]							
$lb/10^3$ bbl refining capacity	Neg	Neg	Neg	28	Neg	Neg	Neg
$kg/10^3$ liter refining capacity	Neg	Neg	Neg	0.080	Neg	Neg	Neg
Vessel relief valves[a]							
$lb/10^3$ bbl refining capacity	Neg	Neg	Neg	11	Neg	Neg	Neg
$kg/10^3$ liter refining capacity	Neg	Neg	Neg	0.031	Neg	Neg	Neg
Pump seals[a]							
$lb/10^3$ bbl refining capacity	Neg	Neg	Neg	17	Neg	Neg	Neg
$kg/10^3$ liter refining capacity	Neg	Neg	Neg	0.049	Neg	Neg	Neg
Compressor seals[a]							
$lb/10^3$ bbl refining capacity	Neg Neg	Neg	Neg	5	Neg	Neg	Neg
$kg/10^3$ liter refining capacity	Neg	Neg	Neg	0.014	Neg	Neg	Neg
Miscellaneous (air blowing, sampling, etc.)[a]							
$lb/10^3$ bbl refining capacity	Neg	Neg	Neg	10	Neg	Neg	Neg
$kg/10^3$ liter refining capacity	Neg	Neg	Neg	0.029	Neg	Neg	Neg

[a] Reference 1.

[b] S = Fuel oil sulfur content (weight percent): factors based on 100 percent combustion of sulfur to SO_2 and assumed density of 336 lb/bbl (0.96 kg/liter).

[c] Negligible emission.

[d] s = refinery gas sulfur content ($lb/100 ft^3$): factors based on 100 percent combustion of sulfur to SO_2.

[e] References 1 through 6.

[f] Numbers in parenthesis indicate range or values observed.

[g] Reference 3.

9.1.3 Converting

To meet quantity demands for certain types of petroleum products, it is often necessary to chemically convert the molecular structures of certain hydrocarbons via "cracking" and "reforming" to produce compounds of different structures.

9.1.3.1 Catalytic Cracking[1]–In the cracking operation, large molecules are decomposed by heat, pressure, and catalysis into smaller, lower-boiling molecules. Simultaneously, some of the molecules combine (polymerize) to form larger molecules. Products of cracking are gaseous hydrocarbons, gasoline, gas oil, fuel oil, and coke.

Most catalytic cracking operations in the U.S. today are performed by using four main methods: (1) fixed-bed, a batch operation; (2) moving-bed, typified by thermofor catalytic cracking (TCC) and Houdriflow units; (3) fluidized-bed (FCC); and (4) "once-through" units. The two most widely used units are the moving- and fluidized-bed types, with the latter most predominant.

In a moving-bed cracker, the charge (gas oil) is heated to 900°F under pressure and passed to the reactor where it passes cross-flow to a descending stream of molecular sieve-type catalyst in the form of beads or pellets. The cracked products then pass to a fractionating tower where the various compounds are tapped off. Meanwhile, the spent catalyst flows through a regeneration zone where coke deposits are burned off in a continuous process. The regenerated catalyst is then conveyed to storage bins atop the reactor vessel for reuse.

In fluidized systems, finely powdered catalyst is lifted into the reactor by the incoming heated oil charge, which vaporizes upon contact with the hot catalyst. Spent catalyst settles out in the reactor, is drawn off at a controlled rate, purged with steam, and lifted by an air stream into the regenerator where the deposited coke is burned off.

Emissions–Emissions from cracking unit regenerators consist of particulates (coke and catalyst fines), hydrocarbons, sulfur oxides, carbon monoxide, aldehydes, ammonia, and nitrogen oxides in the combustion gases. In addition, catalyst fines may be discharged by vents on the catalyst handling systems on both TCC and FCC units. Control measures commonly used on regenerators consist of cyclones and electrostatic precipitators to remove particulates and energy-recovery combustors to reduce carbon monoxide emissions. The latter recovers the heat of combustion of the CO to produce refinery process steam.

9.1.3.2 Hydrocracking[2]–The hydrocracker uses a fixed-bed catalytic reactor, wherein cracking occurs in the presence of hydrogen under substantial pressure. The principal functions of the hydrogen are to suppress the formation of heavy residual material and to increase the yield of gasoline by reacting with the cracked products. High-molecular-weight, sulfur-bearing hydrocarbons are also cracked, and the sulfur combines with the hydrogen to form hydrogen sulfide (H_2S). Therefore, waste gas from the hydrocracker contains large amounts of H_2S, which can be processed for removal of sulfur.

9.1.3.3 Catalytic Reforming[1]–In reforming processes, a feedstock of gasoline undergoes molecular rearrangement via catalysis (usually including hydrogen removal) to produce a gasoline of higher quality and octane number. In various fixed-bed and fluidized-bed processes, the catalyst is regenerated continously, in a manner similar to that used with cracking units.

There are essentially no emissions from reforming operations.

9.1.3.4 Polymerization, Alkylation, and Isomerization[1]–Polymerization and alkylation are processes used to produce gasoline from the gaseous hydrocarbons formed during cracking operations. Polymerization joins two or more olefins (noncyclic unsaturated hydrocarbons with C=C double bonds), and alkylation unites an olefin and an iso-paraffin (noncyclic branched-chain hydrocarbon saturated with hydrogen). Isomerization is the process for altering the arrangement of atoms in a molecule without adding or removing anything from the original material, and is usually used in the oil industry to form branched-chain hydrocarbons. A number of catalysts such as phosphoric acid, sulfuric acid, platinum, aluminum chloride, and hydrofluoric acid are used to promote the combination or rearrangement of these light hydrocarbons.

9.1.3.5 Emissions–These three processes, including regeneration of any necessary catalysts, form essentially closed systems and have no unique, major source of atmospheric emissions. However, the highly volatile hydrocarbons handled, coupled with the high process pressures required, make valve stems and pump shafts difficult to seal, and a greater emission rate from these sources can generally be expected in these process areas than would be the average throughout the refinery. The best method for controlling these emissions is the effective maintenance, repair, and replacement of pump seals, valve caulking, and pipe-joint sealer.

9.1.4 Treating

"Hydrogen," "chemical," and "physical" treating are used in the refinery process to remove undesirable impurities such as sulfur, nitrogen, and oxygen to improve product quality.

9.1.4.1 Hydrogen Treating[1]–In this procedure hydrogen is reacted with impurities in compounds to produce removable hydrogen sulfide, ammonia, and water. In addition, the process converts diolefins (gum-forming hydrocarbons with the empirical formula R=C=R) into stable compounds while minimizing saturation of desirable aromatics.

Hydrogenation units are nearly all the fixed-bed type with catalyst replacement or regeneration (by combustion) done intermittently, the frequency of which is dependent upon operating conditions and the product being treated. The hydrogen sulfide produced is removed from the hydrogen stream via extraction and converted to elemental sulfur or sulfuric acid or, when present in small quantities, burned to SO_2 in a flare or boiler firebox.

9.1.4.2 Chemical Treating[1]–Chemical treating is generally classified into four groups: (1) acid treatment, (2) sweetening, (3) solvent extraction, and (4) additives. Acid treatment involves contacting hydrocarbons with sulfuric acid to partially remove sulfur and nitrogen compounds, to precipitate asphaltic or gum-like materials, and to improve color and odor. Spent acid sludges th result are usually converted to ammonium sulfate or sulfuric acid.

Sweetening processes oxidize mercaptans (formula: R-S-H) to disulfide (formula: R-S-S-Ŕ) without actual sulfur removal. In some processes, air and steam are used for agitation in mixing tanks and to reactivate chemical solutions.

Solvent extraction utilizes solvents that have affinities for the undesirable compounds and that can easily be removed from the product stream. Specifically, mercaptan compounds are usually extracted using a strong caustic solution; hydrogen sulfide is removed by a number of commercial processes.

Finally, additives or inhibitors are primarily materials added in small amounts to oxidize mercaptans to disulfide and to retard gum formation.

9.1.4.3 Physical Treating[1] –Some of the many physical methods used to remove impurities include electrical coalescence, filtration, absorption, and air blowing. Specific applications of physical methods are desalting crude oil, removing wax, decolorizing lube oils, and brightening diesel oil.

9.1.4.4 Emissions – Emissions from treating operations consist of SO_2, hydrocarbons, and visible plumes. Emission levels depend on the methods used in handling spent acid and acid sludges, as well as the means employed for recovery or disposal of hydrogen sulfide. Other potential sources of these emissions in treating include catalyst regeneration, air agitation in mixing tanks, and other air blowing operations. Trace amounts of malodorous substances may escape from numerous sources including settling tank vents, purge tanks, waste treatment units, waste-water drains, valves, and pump seals.

Control methods used include: covers for waste water separators; vapor recovery systems for settling and surge tanks; improved maintenance for pumps, valves, etc; and sulfur recovery plants.

9.1.5 Blending[1]

The final major operation in petroleum refining consists of blending the products in various proportions to meet certain specifications, such as vapor pressure, specific gravity, sulfur content, viscosity, octane number, initial boiling point, and pour point.

9.1.5.1 Emissions – Emissions associated with this operation are hydrocarbons that leak from storage vessels, valves, and pumps. Vapor recovery systems and specially built tanks minimize storage emissions; good housekeeping precludes pump and valve leakage.

9.1.6 Miscellaneous Operations[1]

In addition to the four refinery operations described above, there are many process operations connected with all four. These involve the use of cooling towers, blow-down systems, process heaters and boilers, compressors, and process drains. The emissions and controls associated with these operations are listed in Table 9.1-1.

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9.2 NATURAL GAS PROCESSING

by Harry Butcher and Tom Lahre

9.2.1 General[1]

Natural gas from high-pressure wells is usually passed through field separators to remove hydrocarbon condensate and water at the well. Natural gasoline, butane, and propane are usually present in the gas, and gas processing plants are required for the recovery of these liquefiable constituents (see Figure 9.2-1). Natural gas is considered "sour" if hydrogen sulfide is present in amounts greater than 0.25 grain per 100 standard cubic feet. The hydrogen sulfide (H_2S) must be removed (called "sweetening" the gas) before the gas can be utilized. If H_2S is present, the gas is usually sweetened by absorption of the H_2S in an amine solution. Amine processes are used for over 95 percent of all gas sweetening in the United States. Processes such as carbonate processes, solid bed absorbents, and physical absorption methods are employed in the other sweetening plants. Emissions data for sweetening processes other than amine types are very meager.

The major emission sources in the natural gas processing industry are compressor engines and acid gas wastes from gas sweetening plants. Compressor engine emissions are discussed in section 3.3.2; therefore, only gas sweetening plant emissions are discussed here.

9.2.2 Process Description[2,3]

Many chemical processes are available for sweetening natural gas. However, at present, the most widely used method for H_2S removal or gas sweetening is the amine type process (also known as the Girdler process) in which various amine solutions are utilized for absorbing H_2S. The process is summarized in reaction 1 and illustrated in Figure 9.2-2.

$$2\,RNH_2 + H_2S \longrightarrow (RNH_3)_2S \qquad (1)$$

where: R = mono, di, or tri-ethanol

N = nitrogen

H = hydrogen

S = sulfur

The recovered hydrogen sulfide gas stream may be (1) vented, (2) flared in waste gas flares or modern smokeless flares, (3) incinerated, or (4) utilized for the production of elemental sulfur or other commercial products. If the recovered H_2S gas stream is not to be utilized as a feedstock for commercial applications, the gas is usually passed to a tail gas incinerator in which the H_2S is oxidized to sulfur dioxide and then passed to the atmosphere via a stack. For more details, the reader should consult Reference 8.

9.2.3 Emissions[4,5]

Emissions will only result from gas sweetening plants if the acid waste gas from the amine process is flared or incinerated. Most often, the acid waste gas is used as a feedstock in nearby sulfur recovery or sulfuric acid plants.

When flaring or incineration is practiced, the major pollutant of concern is sulfur dioxide. Most plants employ elevated smokeless flares or tail gas incinerators to ensure complete combustion of all waste gas constituents, including virtually 100 percent conversion of H_2S to SO_2. Little particulate, smoke, or hydrocarbons result from these devices, and because gas temperatures do not usually exceed 1200°F (650°C), significant quantities of nitrogen oxides are not formed. Emission factors for gas sweetening plants with smokeless flares or incinerators are presented in Table 9.2-1.

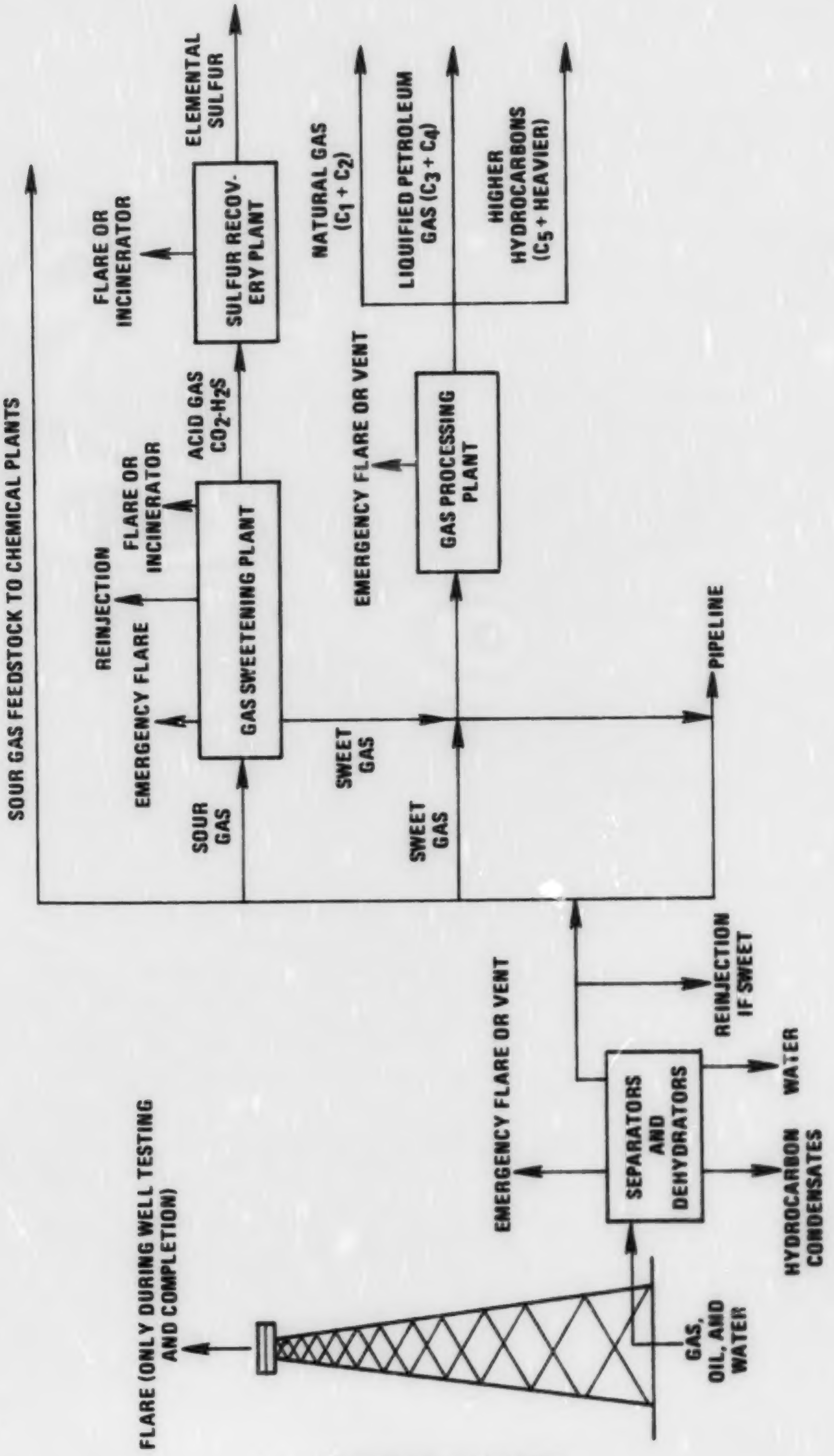
FLARE (ONLY DURING WELL TESTING AND COMPLETION)
GAS, OIL, AND WATER
SEPARATORS AND DEHYDRATORS
EMERGENCY FLARE OR VENT
HYDROCARBON CONDENSATES
WATER
REINJECTION IF SWEET
SOUR GAS FEEDSTOCK TO CHEMICAL PLANTS
SOUR GAS
SWEET GAS
SWEET GAS
PIPELINE
GAS SWEETENING PLANT
EMERGENCY FLARE
REINJECTION
FLARE OR INCINERATOR
ACID GAS CO_2-H_2S
SULFUR RECOVERY PLANT
FLARE OR INCINERATOR
ELEMENTAL SULFUR
GAS PROCESSING PLANT
EMERGENCY FLARE OR VENT
NATURAL GAS ($C_1 + C_2$)
LIQUIFIED PETROLEUM GAS ($C_3 + C_4$)
HIGHER HYDROCARBONS (C_5 + HEAVIER)

Figure 9.2-1. Generalized flow diagram of the natural gas industry.

Table 9.2-1. EMISSION FACTORS FOR GAS SWEETENING PLANTS[a]
EMISSION FACTOR RATING: SULFUR OXIDES: A
ALL OTHER FACTORS: C

Process[b]	Particulates	Sulfur oxides[c] (SO_2)	Carbon monoxide	Hydrocarbons	Nitrogen oxides
Amine					
$lb/10^6\ ft^3$ gas processed	Neg.	1685 S[d]	Neg.	Neg.	Neg.
$kg/10^3\ m^3$ gas processed	Neg.	26.98 S[d]	Neg.	Neg.	Neg.

[a] Emission factors are presented in this section only for smokeless flares and tail gas incinerators on the amine gas sweetening process. Too little emissions information exists to characterize emissions from older, less efficient waste gas flares on the amine process or from other, less common gas sweetening processes. Emission factors for various internal combustion engines utilized in a gas processing plant are given in section 3.3.2. Emission factors for sulfuric acid plants and sulfur recovery plants are given in sections 5.17 and 5.18, respectively.

[b] These factors represent emissions after smokeless flares (with fuel gas and steam injection) or tail gas incinerators and are based on References 2 and 4 through 7.

[c] These factors are based on the assumptions that virtually 100 percent of all H_2S in the acid gas waste is converted to SO_2 during flaring or incineration and that the sweetening process removes essentially 100 percent of the H_2S present in the feedstock.

[d] S is the H_2S content, on a mole percent basis, in the sour gas entering the gas sweetening plant. For example, if the H_2S content is 2 percent, the emission factor would be 1685 times 2, or 3370 lb SO_2 per million cubic feet of sour gas processed. If the H_2S mole percent is unknown, average values from Table 9.2-2 may be substituted.

Note: If H_2S contents are reported in grains per 100 scf or ppm, use the following factors to convert to mole percent:

0.01 mol % H_2S = 6.26 gr H_2S/100 scf at 60°F and 29.92 in. Hg

1 gr/100 scf = 16 ppm (by volume)

To convert to or from metric units, use the following factor:

0.044 gr/100 scf = 1 mg/Nm^3

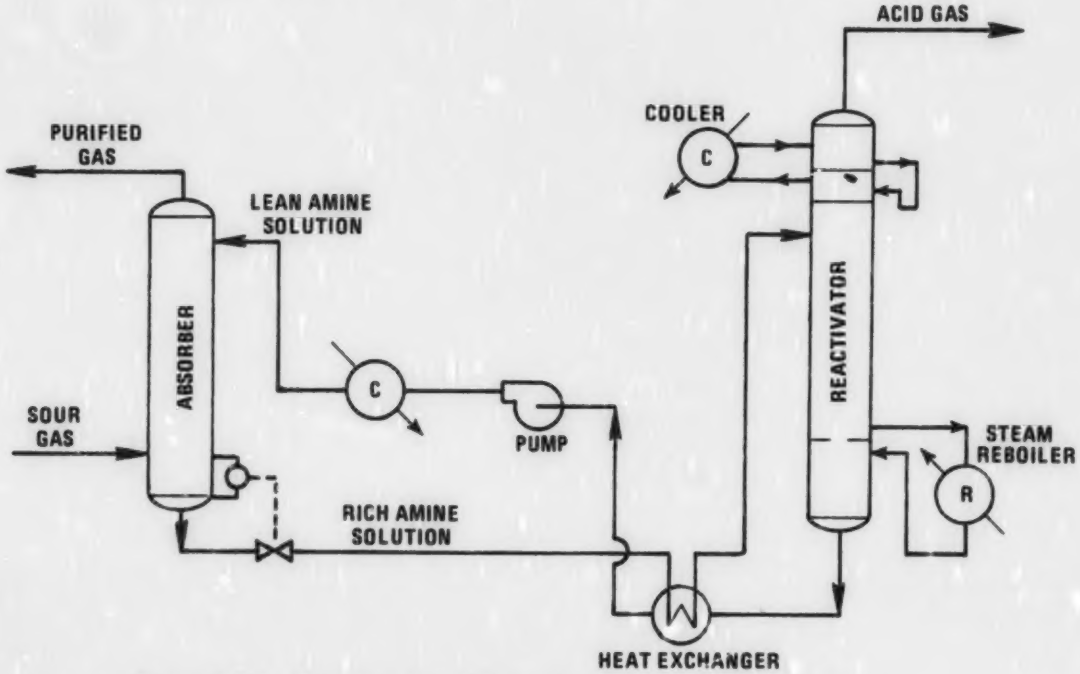

Figure 9.2-2. Flow diagram of the amine process for gas sweetening.

Table 9.2-2. AVERAGE HYDROGEN SULFIDE CONCENTRATIONS IN NATURAL GAS BY AIR QUALITY CONTROL REGION[a]

State	AQCR name	AQCR number	Average H_2S, mol %
Alabama	Mobile-Pensacola-Panama City - Southern Mississippi (Fla., Miss.)	5	3.30
Arizona	Four Corners (Colo., N.M., Utah)	14	0.71
Arkansas	Monroe-El Dorado (La.)	19	0.15
	Shreveport-Texarkana-Tyler (La., Okla., Texas)	22	0.55
California	Metropolitan Los Angeles	24	2.09
	San Joaquin Valley	31	0.89
	South Central Coast	32	3.66
	Southeast Desert	33	1.0
Colorado	Four Corners (Ariz., N.M., Utah)	14	0.71
	Metropolitan Denver	36	0.1
	Pawnee	37	0.49
	San Isabel	38	0.3
	Yampa	40	0.31
Florida	Mobile-Pensacola-Panama City - Southern Mississippi (Ala., Miss.)	5	3.30
Kansas	Northwest Kansas	97	0.005
	Southwest Kansas	100	0.02
Louisiana	Monroe-El Dorado (Ariz.)	19	0.15
	Shreveport-Texarkana-Tyler (Ariz., Okla., Texas)	22	0.55
Michigan	Upper Michigan	126	0.5
Mississippi	Mississippi Delta	134	0.68
	Mobile-Pensacola-Panama City - Southern Mississippi (Ala., Fla.)	5	3.30
Montana	Great Falls	141	3.93
	Miles City	143	0.4
New Mexico	Four Corners (Ariz., Colo., Utah)	14	0.71
	Pecos-Permian Basin	155	0.83
North Dakota	North Dakota	172	1.74[b]
Oklahoma	Northwestern Oklahoma	187	1.1
	Shreveport-Texarkana-Tyler (Ariz., La., Texas)	22	0.55
	Southeastern Oklahoma	188	0.3

Table 9.2-2 (continued). AVERAGE HYDROGEN SULFIDE CONCENTRATIONS IN NATURAL GAS BY AIR QUALITY CONTROL REGION[a]

State	AQCR name	AQCR number	Average H_2S, mol %
Texas	Abilene-Wichita Falls	210	0.055
	Amarillo-Lubbock	211	0.26
	Austin-Waco	212	0.57
	Corpus Christi-Victoria	214	0.59
	Metropolitan Dallas-Fort Worth	215	2.54
	Metropolitan San Antonio	217	1.41
	Midland-Odessa-San Angelo	218	0.63
	Shreveport-Texarkana-Tyler (Ariz., La., Okla.)	22	0.55
Utah	Four Corners (Ariz., Colo., N.M.)	14	0.71
Wyoming	Casper	241	1.262
	Wyoming (except Park, Bighorn and Washakie Counties)	243	2.34

[a] Reference 9.

[b] Sour gas only reported for Burke, Williams, and McKenzie Counties.

[c] Park, Bighorn, and Washakie Counties report gas with an average 23 mol % H_2S content.

Some plants still use older, less efficient waste gas flares. Because these flares usually burn at temperatures lower than necessary for complete combustion, some emissions of hydrocarbons and particulates as well as higher quantities of H_2S can occur. No data are available to estimate the magnitude of these emissions from waste gas flares.

Emissions from sweetening plants with adjacent commercial plants, such as sulfuric acid plants or sulfur recovery plants, are presented in sections 5.17 and 5.18, respectively. Emission factors for internal combustion engines used in gas processing plants are given in section 3.3.2.

Background material for this section was prepared for EPA by Ecology Audits, Inc.[8]

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387<

10. WOOD PROCESSING

Wood processing involves the conversion of raw wood to either pulp, pulpboard, or one of several types of wallboard including plywood, particleboard, or hardboard. This section presents emissions data for chemical wood pulping, for pulpboard and plywood manufacturing, and for woodworking operations. The burning of wood waste in boilers and conical burners is not included as it is discussed in Chapters 1 and 2 of this publication.

10.1 CHEMICAL WOOD PULPING

Revised by Thomas Lahre

10.1.1 General[1]

Chemical wood pulping involves the extraction of cellulose from wood by dissolving the lignin that binds the cellulose fibers together. The principal processes used in chemical pulping are the kraft, sulfite, neutral sulfite semichemical (NSSC), dissolving, and soda; the first three of these display the greatest potential for causing air pollution. The kraft process accounts for about 65 percent of all pulp produced in the United States; the sulfite and NSSC processes, together, account for less than 20 percent of the total. The choice of pulping process is determined by the product being made, by the type of wood species available, and by economic considerations.

10.1.2 Kraft Pulping

10.1.2.1 Process Description[1,2]–The kraft process (see Figure 10.1.2-1) involves the cooking of wood chips under pressure in the presence of a cooking liquor in either a batch or a continuous digester. The cooking liquor, or "white liquor," consisting of an aqueous solution of sodium sulfide and sodium hydroxide, dissolves the lignin that binds the cellulose fibers together.

When cooking is completed, the contents of the digester are forced into the blow tank. Here the major portion of the spent cooking liquor, which contains the dissolved lignin, is drained, and the pulp enters the initial stage of washing. From the blow tank the pulp passes through the knotter where unreacted chunks of wood are removed. The pulp is then washed and, in some mills, bleached before being pressed and dried into the finished product.

It is economically necessary to recover both the inorganic cooking chemicals and the heat content of the spent "black liquor," which is separated from the cooked pulp. Recovery is accomplished by first concentrating the liquor to a level that will support combustion and then feeding it to a furnace where burning and chemical recovery take place.

Initial concentration of the weak black liquor, which contains about 15 percent solids, occurs in the multiple-effect evaporator. Here process steam is passed countercurrent to the liquor in a series of evaporator tubes that increase the solids content to 40 to 55 percent. Further concentration is then effected in the direct contact evaporator. This is generally a scrubbing device (a cyclonic or venturi scrubber or a cascade evaporator) in which hot combustion gases from the recovery furnace mix with the incoming black liquor to raise its solids content to 55 to 70 percent.

The black liquor concentrate is then sprayed into the recovery furnace where the organic content supports combustion. The inorganic compounds fall to the bottom of the furnace and are discharged to the smelt dissolving tank to form a solution called "green liquor." The green liquor is then conveyed to a causticizer where slaked lime (calcium hydroxide) is added to convert the solution back to white liquor, which can be reused in subsequent cooks. Residual lime sludge from the causticizer can be recycled after being dewatered and calcined in the hot lime kiln.

Many mills need more steam for process heating, for driving equipment, for providing electric power, etc., than can be provided by the recovery furnace alone. Thus, conventional industrial boilers that burn coal, oil, natural gas, and in some cases, bark and wood waste are commonly employed.

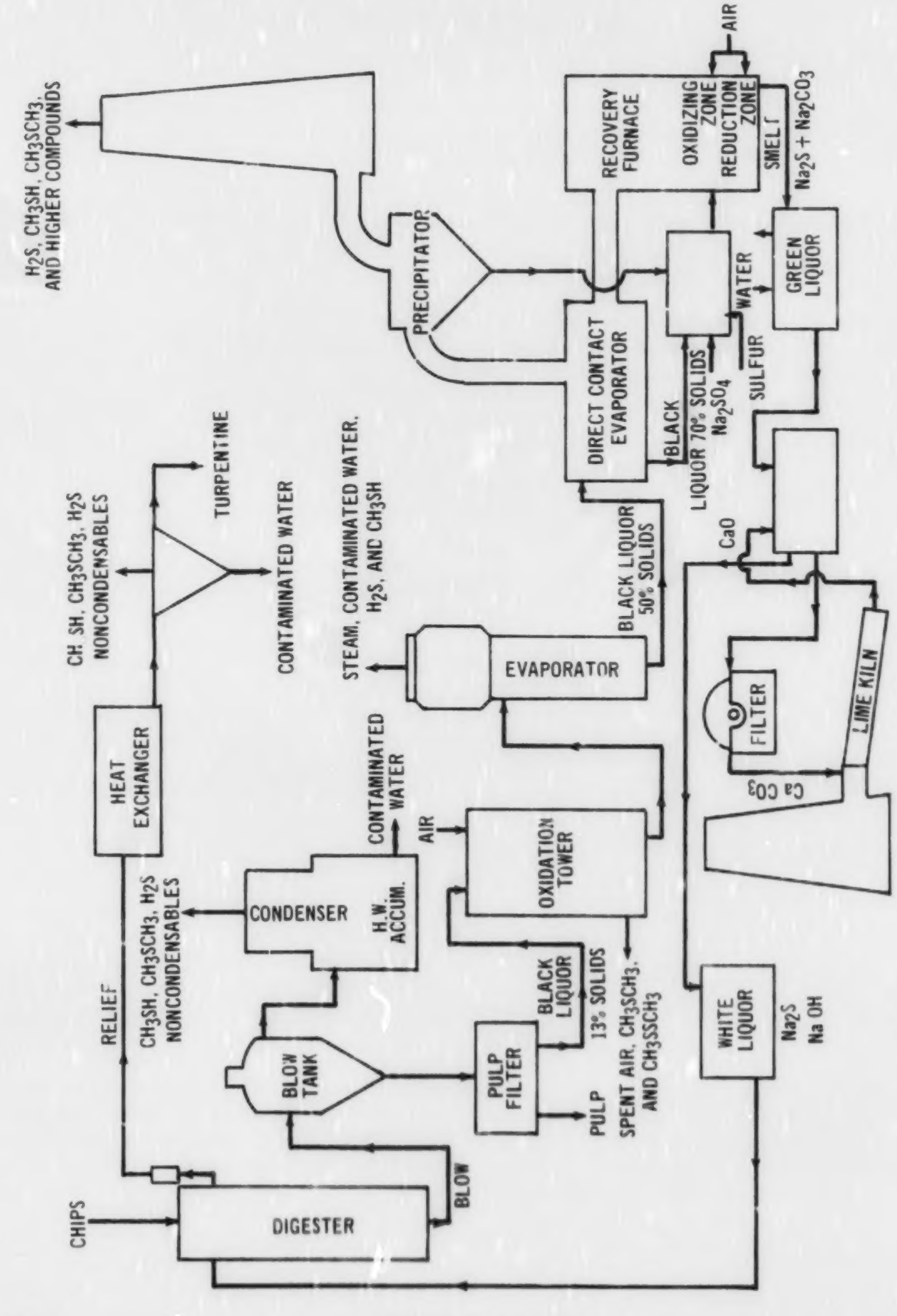
CHIPS
DIGESTER
BLOW
RELIEF
BLOW TANK
PULP FILTER
PULP
BLACK LIQUOR
13% SOLIDS
SPENT AIR, CH_3SCH_3, AND CH_3SSCH_3
CH_3SH, CH_3SCH_3, H_2S NONCONDENSABLES
CONDENSER
H.W. ACCUM.
CONTAMINATED WATER
AIR
OXIDATION TOWER
HEAT EXCHANGER
CH. SH, CH_3SCH_3, H_2S NONCONDENSABLES
TURPENTINE
CONTAMINATED WATER
STEAM, CONTAMINATED WATER, H_2S, AND CH_3SH
EVAPORATOR
BLACK LIQUOR 50% SOLIDS
DIRECT CONTACT EVAPORATOR
BLACK LIQUOR 70% SOLIDS
Na_2SO_4
SULFUR
WATER
PRECIPITATOR
H_2S, CH_3SH, CH_3SCH_3, AND HIGHER COMPOUNDS
RECOVERY FURNACE
OXIDIZING ZONE
REDUCTION ZONE
AIR
SMELT
$Na_2S + Na_2CO_3$
GREEN LIQUOR
CaO
FILTER
LIME KILN
Ca CO_3
WHITE LIQUOR
Na_2S
Na OH

Figure 10.1.2-1. Typical kraft sulfate pulping and recovery process.

10.1.2.2. Emission and Controls[1-6] Particulate emissions from the kraft process occur primarily from the recovery furnace, the lime kiln, and the smelt dissolving tank. These emissions consist mainly of sodium salts but include some calcium salts from the lime kiln. They are caused primarily by the carryover of solids plus the sublimation and condensation of the inorganic chemicals.

Particulate control is provided on recovery furnaces in a variety of ways. In mills where either a cyclonic scrubber or cascade evaporator serves as the direct contact evaporator, further control is necessary as these devices are generally only 20 to 50 percent efficient for particulates. Most often in these cases, an electrostatic precipitator is employed after the direct contact evaporator to provide an overall particulate control efficiency of 85 to ≥ 99 percent. In a few mills, however, a venturi scrubber is utilized as the direct contact evaporator and simultaneously provides 80 to 90 percent particulate control. In either case auxiliary scrubbers may be included after the precipitator or the venturi scrubber to provide additional control of particulates.

Particulate control on lime kilns is generally accomplished by scrubbers. Smelt dissolving tanks are commonly controlled by mesh pads but employ scrubbers when further control is needed.

The characteristic odor of the kraft mill is caused in large part by the emission of hydrogen sulfide. The major source is the direct contact evaporator in which the sodium sulfide in the black liquor reacts with the carbon dioxide in the furnace exhaust. The lime kiln can also be a potential source as a similar reaction occurs involving residual sodium sulfide in the lime mud. Lesser amounts of hydrogen sulfide are emitted with the noncondensible off-gasses from the digesters and multiple-effect evaporators.

The kraft-process odor also results from an assortment of organic sulfur compounds, all of which have extremely low odor thresholds. Methyl mercaptan and dimethyl sulfide are formed in reactions with the wood component lignin. Dimethyl disulfide is formed through the oxidation of mercaptan groups derived from the lignin. These compounds are emitted from many points within a mill; however, the main sources are the digester/blow tank systems and the direct contact evaporator.

Although odor control devices, per se, are not generally employed in kraft mills, control of reduced sulfur compounds can be accomplished by process modifications and by optimizing operating conditions. For example, black liquor oxidation systems, which oxidize sulfides into less reactive thiosulfates, can considerably reduce odorous sulfur emissions from the direct contact evaporator, although the vent gases from such systems become minor odor sources themselves. Noncondensible odorous gases vented from the digester/blow tank system and multiple-effect evaporators can be destroyed by thermal oxidation, usually by passing them through the lime kiln. Optimum operation of the recovery furnace, by avoiding overloading and by maintaining sufficient oxygen residual and turbulence, significantly reduces emissions of reduced sulfur compounds from this source. In addition, the use of fresh water instead of contaminated condensates in the scrubbers and pulp washers further reduces odorous emissions. The effect of any of these modifications on a given mill's emissions will vary considerably.

Several new mills have incorporated recovery systems that eliminate the conventional direct contact evaporators. In one system, preheated combustion air rather than flue gas provides direct contact evaporation. In the other, the multiple-effect evaporator system is extended to replace the direct contact evaporator altogether. In both of these systems, reduced sulfur emissions from the recovery furnace/direct contact evaporator reportedly can be reduced by more than 95 percent from conventional uncontrolled systems.

Sulfur dioxide emissions result mainly from oxidation of reduced sulfur compounds in the recovery furnace. It is reported that the direct contact evaporator absorbs 50 to 80 percent of these emissions; further scrubbing, if employed, can reduce them another 10 to 20 percent.

Potential sources of carbon monoxide emissions from the kraft process include the recovery furnace and lime kilns. The major cause of carbon monoxide emissions is furnace operation well above rated capacity, making it impossible to maintain oxidizing conditions.

Some nitrogen oxides are also emitted from the recovery furnace and lime kilns although the amounts are relatively small. Indications are that nitrogen oxides emissions from each of these sources are on the order of 1 pound per air-dried ton (0.5 kg/air-dried MT) of pulp produced.[5,6]

A major source of emissions in a kraft mill is the boiler for generating auxiliary steam and power. The fuels used are coal, oil, natural gas, or bark/wood waste. Emission factors for boilers are presented in Chapter 1.

Table 10.1.2-1 presents emission factors for a conventional kraft mill. The most widely used particulate controls devices are shown along with the odor reductions resulting from black liquor oxidation and incineration of noncondensible off-gases.

10.1.3 Acid Sulfite Pulping

by Tom Lahre

10.1.3.1 Process Description[14] - The production of acid sulfite pulp proceeds similarly to kraft pulping except that different chemicals are used in the cooking liquor. In place of the caustic solution used to dissolve the lignin in the wood, sulfurous acid is employed. To buffer the cooking solution, a bisulfite of sodium, magnesium, calcium, or ammonium is used. A simplified flow diagram of a magnesium-base process is shown in Figure 10.1.3-1.

Digestion is carried out under high pressure and high temperature in either batch-mode or continuous digesters in the presence of a sulfurous acid-bisulfite cooking liquor. When cooking is comleted, the digester is either discharged at high pressure into a blow pit or its contents are pumped out at a lower pressure into a dump tank. The spent sulfite liquor (also called red liquor) then drains through the bottom of the tank and is either treated and disposed, incinerated, or sent to a plant for recovery of heat and chemicals. The pulp is then washed and processed through screens and centrifuges for removal of knots, bundles of fibers, and other materials. It subsequently may be bleached, pressed, and dried in paper-making operations.

Because of the variety of bases employed in the cooking liquor, numerous schemes for heat and/or chemical recovery have evolved. In calcium-base systems, which are used mostly in older mills, chemical recovery is not practical, and the spent liquor is usually discarded or incinerated. In ammonium-base operations, heat can be recovered from the spent liquor through combustion, but the ammonium base is consumed in the process. In sodium- or magnesium-base operations heat, sulfur, and base recovery are all feasible.

If recovery is practiced, the spent weak red liquor (which contains more than half of the raw materials as dissolved organic solids) is concentrated in a multiple-effect evaporator and direct contact evaporator to 55 to 60 percent solids. Strong liquor is sprayed into a furnace and burned, producing steam for the digesters, evaporators, etc., and to meet the mills power requirements.

When magnesium base liquor is burned, a flue gas is produced from which magnesium oxide is recovered in a multiple cyclone as fine white powder. The magnesium oxide is then water-slaked and used as circulating liquor in a series of venturi scrubbers which are designed to absorb sulfur dioxide from the flue gas and form a bisulfite solution for use in the cook cycle. When sodium-base liquor is burned, the inorganic compounds are recovered as a molten smelt containing sodium sulfide and sodium carbonate. This smelt may be processed further and used to absorb sulfur dioxide from the flue gas and sulfur burner. In some sodium-base mills, however, the smelt may be sold to a nearby kraft mill as raw material for producing green liquor.

Table 10.1.2-1. EMISSION FACTORS FOR SULFATE PULPING[a]

(unit weights of air-dried unbleached pulp)

EMISSION FACTOR RATING: A

Source	Type control	Particulates[b]		Sulfur dioxide (SO_2)[c]		Carbon monoxide[d]		Hydrogen sulfide ($S^=$)[e]		RSH, RSR, RSSR ($S^=$)[e,f]	
		lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Digester relief and blow tank	Untreated[g]	–	–	–	–	–	–	0.1	0.05	1.5	0.75
Brown stock washers	Untreated	–	–	0.01	0.005	–	–	0.02	0.01	0.2	0.1
Multiple effect evaporators	Untreated[g]	–	–	0.01	0.005	–	–	0.1	0.05	0.4	0.2
Recovery boiler and direct contact evaporator	Untreated[h]	150	75	5	2.5	2 - 60	1 - 30	12[i]	6[i]	1[i]	0.5[i]
	Venturi scrubber[j]	47	23.5	5	2.5	2 - 60	1 - 30	12[i]	6[i]	1[i]	0.5[i]
	Electrostatic precipitator	8	4	5	2.5	2 - 60	1 - 30	12[i]	6[i]	1[i]	0.5[i]
	Auxiliary scrubber	3 - 15[k]	1.5 - 7.5[k]	3	1.5	2 - 60	1 - 30	12[i]	6[i]	1[i]	0.5[i]
Smelt dissolving tank	Untreated	5	2.5	0.1	0.05	–	–	0.04	0.02	0.4	0.2
	Mesh pad	1	0.5	0.1	0.05	–	–	0.04	0.02	0.4	0.2
Lime kilns	Untreated	45	22.5	0.3	0.15	10	5	0.5	0.25	0.25	0.125
	Scrubber	3	1.5	0.2	0.1	10	5	0.5	0.25	0.25	0.125
Turpentine condenser	Untreated	–	–	–	–	–	–	0.01	0.005	0.5	0.25
Miscellaneous sources[l]	Untreated	–	–	–	–	–	–	–	–	0.5	0.25

[a] For more detailed data on specific types of mills, consult Reference 1.

[b] References 1, 7, 8.

[c] References 1, 7, 9, 10.

[d] References 6, 11. Use higher value for overloaded furnaces.

[e] References 1, 4, 7-10, 12, 13. These reduced sulfur compounds are usually expressed as sulfur.

[f] RSH-methyl mercaptan; RSR-dimethyl sulfide; RSSR-dimethyl disulfide.

[g] If the noncondensible gases from these sources are vented to the lime kiln, recovery furnace, or equivalent, the reduced sulfur compounds are destroyed.

[h] These factors apply when either a cyclonic scrubber or cascade evaporator is used for direct contact evaporation with no further controls.

[i] These reduced sulfur compounds (TRS) are typically reduced by 50 percent when black liquor oxidation is employed but can be cut by 90 to 99 percent when oxidation is complete and the recovery furnace is operated optimally.

[j] These factors apply when a venturi scrubber is used for direct contact evaporation with no further controls.

[k] Use 15(7.5) when the auxiliary scrubber follows a venturi scrubber and 3(1.5) when employed after an electrostatic precipitator.

[l] Insludes knotter vents, brownstock seal tanks, etc. When black liquor oxidation is included, a factor of 0.6(0.3) should be used.

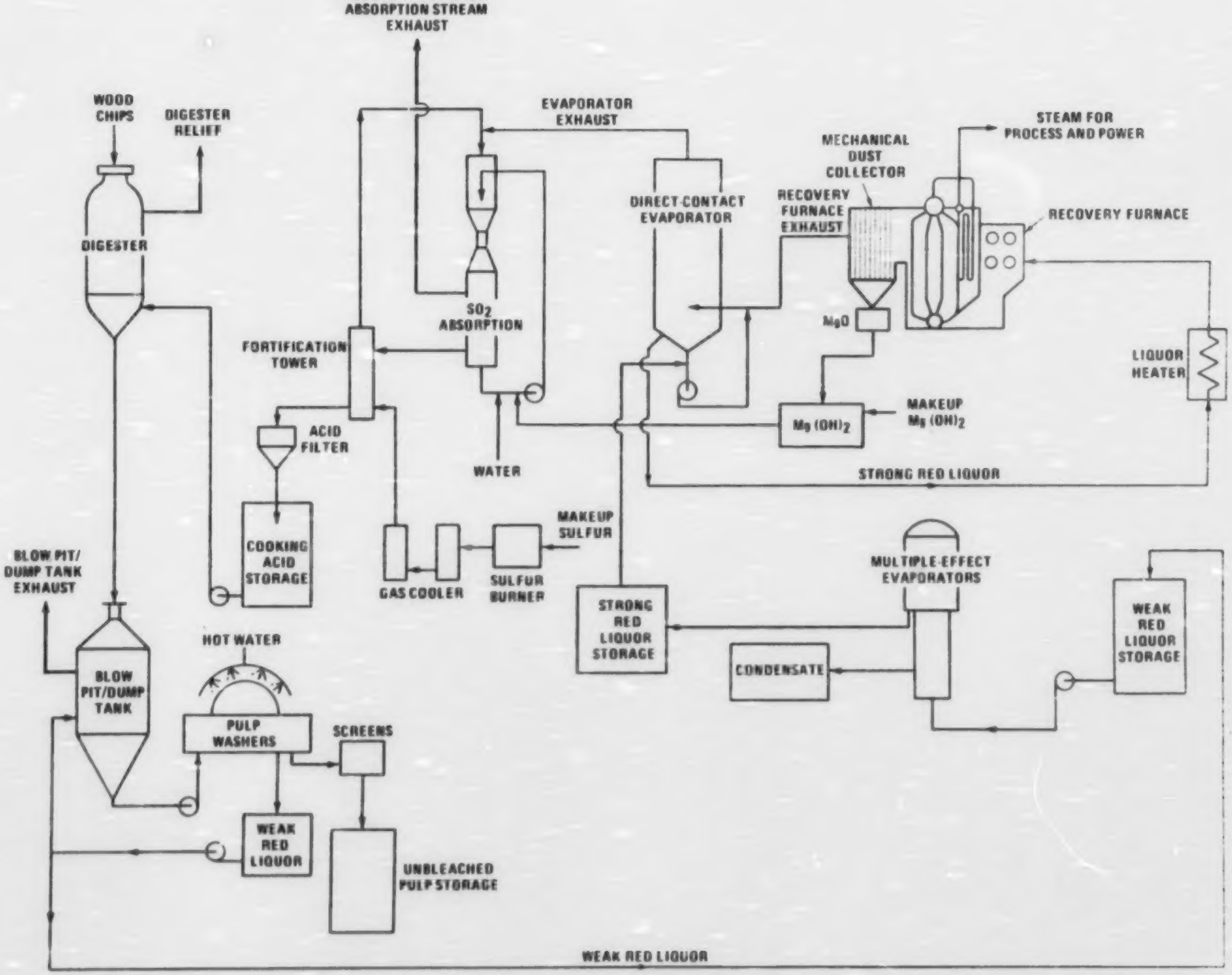
RECOVERY FURNACE/ ABSORPTION STREAM EXHAUST
WOOD CHIPS
DIGESTER RELIEF
DIGESTER
EVAPORATOR EXHAUST
STEAM FOR PROCESS AND POWER
MECHANICAL DUST COLLECTOR
RECOVERY FURNACE EXHAUST
DIRECT-CONTACT EVAPORATOR
RECOVERY FURNACE
SO_2 ABSORPTION
FORTIFICATION TOWER
MgO
LIQUOR HEATER
MAKEUP $Mg(OH)_2$
$Mg(OH)_2$
ACID FILTER
WATER
STRONG RED LIQUOR
MAKEUP SULFUR
COOKING ACID STORAGE
GAS COOLER
SULFUR BURNER
MULTIPLE-EFFECT EVAPORATORS
BLOW PIT/ DUMP TANK EXHAUST
STRONG RED LIQUOR STORAGE
WEAK RED LIQUOR STORAGE
CONDENSATE
HOT WATER
BLOW PIT/DUMP TANK
PULP WASHERS
SCREENS
WEAK RED LIQUOR
UNBLEACHED PULP STORAGE
WEAK RED LIQUOR

Figure 10.1.3-1. Simplified process flow diagram of magnesium-base process employing chemical and heat recovery.

If recovery is not practiced, an acid plant of sufficient capacity to fulfill the mill's total sulfite requirement is necessary. Normally, sulfur is burned in a rotary or spray burner. The gas produced is then cooled by heat exchangers plus a water spray and then absorbed in a variety of different scrubbers containing either limestone or a solution of the base chemical. Where recovery is practiced, fortification is accomplished similarly, although a much smaller amount of sulfur dioxide must be produced to make up for that lost in the process.

10.1.3.2 Emissions and Controls[14] - Sulfur dioxide is generally considered the major pollutant of concern from sulfite pulp mills. The characteristic "kraft" odor is not emitted because volatile reduced sulfur compounds are not products of the lignin-bisulfite reaction.

One of the major SO_2 sources is the digester and blow pit or dump tank system. Sulfur dioxide is present in the intermittent digester relief gases as well as in the gases given off at the end of the cook when the digester contents are discharged into the blow pit or dump tank. The quantity of sulfur oxide evolved and emitted to the atmosphere in these gas streams depends on the pH of the cooking liquor, the pressure at which the digester contents are discharged, and the effectiveness of the absorption systems employed for SO_2 recovery. Scrubbers can be installed that reduce SO_2 from this source by as much as 99 percent.

Another source of sulfur dioxide emissions is the recovery system. Since magnesium-, sodium-, and ammonium-base recovery systems all utilize absorption systems to recover SO_2 generated in the recovery furnace, acid fortification towers, multiple-effect evaporators, etc., the magnitude of SO_2 emissions depends on the desired efficiency of these systems. Generally, such absorption systems provide better than 95 percent sulfur recovery to minimize sulfur makeup needs.

The various pulp washing, screening, and cleaning operations are also potential sources of SO_2. These operations are numerous and may account for a significant fraction of a mill's SO_2 emissions if not controlled.

The only significant particulate source in the pulping and recovery process is the absorption system handling the recovery furnace exhaust. Less particulate is generated in ammonium-base systems than magnesium- or sodium-base systems as the combustion productions are mostly nitrogen, water vapor, and sulfur dioxide.

Other major sources of emissions in a sulfite pulp mill include the auxiliary power boilers. Emission factors for these boilers are presented in Chapter 1.

Emission factors for the various sulfite pulping operations are shown in Table 10.1.3-1.

10.1.4 Neutral Sulfite Semichemical (NSSC) Pulping

10.1.4.1 Process Description[1,7,15,16] - In this process, the wood chips are cooked in a neutral solution of sodium sulfite and sodium bicarbonate. The sulfite ion reacts with the lignin in the wood, and the sodium bicarbonate acts as a buffer to maintain a neutral solution. The major difference between this process (as well as all semichemical techniques) and the kraft and acid sulfite processes is that only a portion of the lignin is removed during the cook, after which the pulp is further reduced by mechanical disintegration. Because of this, yields as high as 60 to 80 percent can be achieved as opposed to 50 to 55 percent for other chemical processes.

Table 10.1.3-1. EMISSION FACTORS FOR SULFITE PULPING[a]

Source	Base	Control	Emission factor[b]				Emission factor rating
			Particulate		Sulfur Dioxide		
			lb/ADUT	kg/ADUMT	lb/ADUT	kg/ADUMT	
Digester blow pit or dump tank[c]	All	None	Neg[d]	Neg	10-70	5-35	C
	MgO	Process change[e]	Neg	Neg	2-6	1-3	C
	MgO	Scrubber	Neg	Neg	1	0.5	B
	MgO	Process change and scrubber	Neg	Neg	0.2	0.1	B
	MgO	All exhaust vented through recovery system	Neg	Neg	0	0	A
	NH_3	Process change	Neg	Neg	25	12.5	D
	NH_3	Process change and scrubber	Neg	Neg	0.4	0.2	B
	Na	Process change and scrubber	Neg	Neg	2	1	C
	Ca	Unknown	Neg	Neg	67	33.5	C
Recovery system[f]	MgO	Multiclone and venturi scrubbers	2	1	9	4.5	A
	NH_3	Ammonia absorption and mist eliminator	0.7	0.35	7	3.5	B
	Na	Sodium carbonate scrubber	4	2	2	1	C
Acid plant[g]	NH_3	Scrubber	Neg	Neg	0.3	0.2	C
	Na	Unknown[h]	Neg	Neg	0.2	0.1	D
	Ca	Jenssen scrubber	Neg	Neg	8	4	C
Other sources[i]	All	None	Neg	Neg	12	6	D

[a] All emission factors represent long-term average emissions.

[b] Factors expressed in terms of lb (kg) of pollutant per air dried unbleached ton (MT) of pulp. All factors are based on data in Reference 14.

[c] These factors represent emissions that occur after the cook is completed and when the digester contents are discharged into the blow pit or dump tank. Some relief gases are vented from the digester during the cook cycle, but these are usually transferred to pressure accumulators, and the SO_2 therein is reabsorbed for use in the cooking liquor. These factors represent long-term average emissions; in some mills, the actual emissions will be intermittent and for short time periods.

[d] Negligible emissions.

[e] Process changes may include such measures as raising the pH of the cooking liquor, thereby lowering the free SO_2, relieving the pressure in the digester before the contents are discharged, and pumping out the digester contents instead of blowing them out.

[f] The recovery system at most mills is a closed system that includes the recovery furnace, direct contact evaporator, multiple-effect evaporator, acid fortification tower, and SO_2 absorption scrubbers. Generally, there will only be one emission point for the entire recovery system. These factors are long-term averages and include the high SO_2 emissions during the periodic purging of the recovery system.

[g] Acid plants are necessary in mills that have no or insufficient recovery systems.

[h] Control is practiced, but type of control is unknown.

[i] Includes miscellaneous pulping operations such as knotters, washers, screens, etc.

The NSSC process varies from mill to mill. Some mills dispose of their spent liquor, some mills recover the cooking chemicals, and some, which are operated in conjunction with kraft mills, mix their spent liquor with the kraft liquor as a source of makeup chemicals. When recovery is practiced, the steps involved parallel those of the sulfite process.

10.1.4.2 Emissions and Controls[1,7,15,16] Particulate emissions are a potential problem only when recovery systems are employed. Mills that do practice recovery, but are not operated in conjunction with kraft operations often utilize fluidized bed reactors to burn their spent liquor. Because the flue gas contains sodium sulfate and sodium carbonate dust, efficient particulate collection may be included to facilitate chemical recovery.

A potential gaseous pollutant is sulfur dioxide. The absorbing towers, digester/blow tank system, and recovery furnace are the main sources of this pollutant with the amounts emitted dependent upon the capability of the scrubbing devices installed for control and recovery.

Hydrogen sulfide can also be emitted from NSSC mills using kraft-type recovery furnaces. The main potential source is the absorbing tower where a significant quantity of hydrogen sulfide is liberated as the cooking liquor is made. Other possible sources include the recovery furnace, depending on the operating conditions maintained, as well as the digester/blow tank system in mills where some green liquor is used in the cooking process. Where green liquor is used, it is also possible that significant quantities of mercaptans will be produced. Hydrogen sulfide emissions can be eliminated if burned to sulfur dioxide prior to entering the absorbing systems.

Because the NSSC process differs greatly from mill to mill, and because of the scarcity of adequate data, no emission factors are presented.

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10.2 PULPBOARD

10.2.1 General[1]

Pulpboard manufacturing involves the fabrication of fibrous boards from a pulp slurry. This includes two distinct types of product, paperboard and fiberboard. Paperboard is a general term that describes a sheet 0.012 inch (0.30 mm) or more in thickness made of fibrous material on a paper-forming machine.[2] Fiberboard, also referred to as particle board, is thicker than paperboard and is made somewhat differently.

There are two distinct phases in the conversion of wood to pulpboard: (1) the manufacture of pulp from raw wood and (2) the manufacture of pulpboard from the pulp. This section deals only with the latter as the former is covered under the section on the wood pulping industry.

10.2.2 Process Description[1]

In the manufacture of paperboard, the stock is sent through screens into the head box, from which it flows onto a moving screen. Approximately 15 percent of the water is removed by suction boxes located under the screen. Another 50 to 60 percent of the moisture content is removed in the drying section. The dried board then enters the calendar stack, which imparts the final surface to the product.

In the manufacture of fiberboard, the slurry that remains after pulping is washed and sent to the stock chests where sizing is added. The refined fiber from the stock chests is fed to the head box of the board machine. The stock is next fed onto the forming screens and sent to dryers, after which the dry product is finally cut and fabricated.

10.2.3 Emissions[1]

Emissions from the paperboard machine consist mainly of water vapor; little or no particulate matter is emitted from the dryers.[3-5] Particulates are emitted, however, from the fiberboard drying operation. Additional particulate emissions occur from the cutting and sanding operations. Emission factors for these operations are given in section 10.4. Emission factors for pulpboard manufacturing are shown in Table 10.2-1.

Table 10.2-1. PARTICULATE EMISSION FACTORS FOR PULPBOARD MANUFACTURING[a]
EMISSION FACTOR RATING: E

Type of product	Emissions	
	lb/ton	kg/MT
Paperboard	Neg	Neg
Fiberboard[b]	0.6	0.3

[a] Emission factors expressed as units per unit weight of finished product.
[b] Reference 1.

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10.3 PLYWOOD VENEER AND LAYOUT OPERATIONS

By Thomas Lahre

10.3.1 Process Description[1]

Plywood is a material made of several thin wood veneers bonded together with an adhesive. Its uses are many and include wall sidings, sheathing, roof-decking, concrete-formboards, floors, and containers.

During the manufacture of plywood, incoming logs are sawed to desired length, debarked, and then peeled into thin, continuous veneers of uniform thickness. (Veneer thicknesses of 1/45 to 1/5 inch are common.) These veneers are then transported to special dryers where they are subjected to high temperatures until dried to a desired moisture content. After drying, the veneers are sorted, patched, and assembled in layers with some type of thermosetting resin used as the adhesive. The veneer assembly is then transferred to a hot press where, under presssure and steam heat, the plywood product is formed. Subsequently, all that remains is trimming, sanding, and possibly some sort of finishing treatment to enhance the usefullness of the plywood.

10.3.2 Emissions[2,3]

The main sources of emissions from plywood manufacturing are the veneer drying and sanding operations. A third source is the pressing operation although these emissions are considered minor.

The major pollutants emitted from veneer dryers are organics. These consist of two discernable fractions: (1) condensibles, consisting of wood resins, resin acids, and wood sugars, which form a blue haze upon cooling in the atmosphere, and (2) volatiles, which are comprised of terpines and unburned methane—the latter occurring when gas-fired dryers are employed. The amounts of these compounds produced depends on the wood species dried, the drying time, and the nature and operation of the dryer itself. In addition, negligible amounts of fine wood fibers are also emitted during the drying process.

Sanding operations are a potential source of particulate emissions (see section 10.4). Emission factors for plywood veneer dryers without controls are given in Table 10.3-1.

Table 10.3-1. EMISSION FACTORS FOR PLYWOOD MANUFACTURING
EMISSION FACTOR RATING: B

Source	Organic compound[a,b]			
	Condensible		Volatile	
	$lb/10^4\ ft^2$	$kg/10^3\ m^2$	$lb/10^4\ ft^2$	$kg/10^3\ m^2$
Veneer dryers	3.6	1.9	2.1	1.1

[a] Emission factors expressed in pounds of pollutant per 10,000 square feet of 3/8-in. plywood produced (kilograms per 1,000 square meters on a 1-cm basis).

[b] References 2 and 3.

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10.4 WOODWORKING OPERATIONS

by Tom Lahre

10.4.1 General[1-5]

"Woodworking," as defined in this section, includes any operation that involves the generation of small wood waste particles (shavings, sanderdust, sawdust, etc.) by any kind of mechanical manipulation of wood, bark, or wood byproducts. Common woodworking operations include sawing, planing, chipping, shaping, moulding, hogging, latheing, and sanding. Woodworking operations are found in numerous industries such as sawmills; plywood, particleboard, and hardboard plants; and furniture manufacturing plants.

Most plants engaged in woodworking employ pneumatic transfer systems to remove the generated wood waste from the immediate proximity of each woodworking operation. These systems are necessary as a housekeeping measure to eliminate the vast quantity of waste material that would otherwise accumulate. They are also a convenient means of transporting the waste material to common collection points for ultimate disposal. Large diameter cyclones have historically been the primary means of separating the waste material from the airstreams in the pneumatic transfer systems, although baghouses have recently been installed in some plants for this purpose.

The waste material collected in the cyclones or baghouses may be burned in wood waste boilers, utilized in the manufacture of other products (such as pulp or particleboard), or incinerated in conical (teepee/wigwam) burners. The latter practice is declining with the advent of more stringent air pollution control regulations and because of the economic attractiveness of utilizing wood waste as a resource.

10.4.2 Emissions[1-6]

The only pollutant of concern in woodworking operations is particulate matter. The major emission points are the cyclones utilized in the pneumatic transfer systems. The quantity of particulate emissions from a given cyclone will depend on the dimensions of the cyclone, the velocity of the airstream, and the nature of the operation generating the waste. Typical large-diameter cyclones found in the industry will only effectively collect particles greater than 40 micrometers in diameter. Baghouses, when employed, collect essentially all of the waste material in the airstream.

It is difficult to describe a typical woodworking operation and the emissions resulting therefrom because of the many types of operations that may be required to produce a given type of product and because of the many variations that may exist in the pneumatic transfer and collection systems. For example, the waste from numerous pieces of equipment often feed into the same cyclone, and it is common for the material collected in one or several cyclones to be conveyed to another cyclone. It is also possible for portions of the waste generated by a single operation to be directed to different cyclones.

Because of this complexity, it is useful when evaluating emissions from a given facility to consider the waste handling cyclones as air pollution sources instead of the various woodworking operations that actually generate the particulate matter. Emission factors for typical large-diameter cyclones utilized for waste collection in woodworking operations are given in Table 10.4-1.

Emission factors for wood waste boilers, conical burners, and various drying operations–often found in facilities employing woodworking operations–are given in sections 1.6, 2.3, 10.2, and 10.3.

Table 10.4.1. PARTICULATE EMISSION FACTORS FOR LARGE DIAMETER CYCLONES[a] IN WOODWORKING INDUSTRY

Types of waste handled	Particulate emissions[b]			
	gr/scf	g/$\underline{N}$m^3	lb/hr	kg/hr
Sanderdust[c]	0.055[d]	0.126[d]	5[e]	2.3[e]
Other[f]	0.03[g]	0.07[g]	2[h]	0.91[h]

[a] Typical waste collection cyclones range from 4 to 16 feet (1.2 to 4.9 meters) in diameter and employ airflows ranging from 2,000 to 26,000 standard cubic feet (57 to 740 normal cubic meters) per minute. Note: if baghouses are used for waste collection, particulate emissions will be negligible.

[b] Based on information in References 1 through 3.

[c] These factors should be used whenever waste from sanding operations is fed directly into the cyclone in question.

[d] These factors represent the median of all values observed. The observed values range from 0.005 to 0.16 gr/scf (0.0114 to 0.37 g/$\underline{N}$m^3).

[e] These factors represent the median of all values observed. The observed values range from 0.2 to 30 lb/hr (0.09 to 13.6 kg/hr).

[f] These factors should be used for cyclones handling waste from all operations other than sanding. This includes cyclones that handle waste (including sanderdust) already collected by another cyclone.

[g] These factors represent the median of all values observed. The observed values range from 0.001 to 0.16 gr/scf (0.002 to 0.37 g/$\underline{N}$m^3).

[h] These factors represent the median of all values observed. The observed values range from 0.03 to 24 lb/hr (0.014 to 10.9 kg/hr).

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MISCELLANEOUS SOURCES

This chapter contains emission factor information on those source categories that differ substantially from – and hence cannot be grouped with – the other "stationary" sources discussed in this publication. These "miscellaneous" emitters (both natural and man-made) are almost exclusively "area sources", that is, their pollutant generating process(es) are dispersed over large land areas (for example, hundreds of acres, as in the case of forest wildfires), as opposed to sources emitting from one or more stacks with a total emitting area of only several square feet. Another characteristic these sources have in common is the nonapplicability, in most cases, of conventional control methods, such as wet/dry equipment, fuel switching, process changes, etc. Instead, control of these emissions, where possible at all, may include such techniques as modification of agricultural burning practices, paving with asphalt or concrete, or stabilization of dirt roads. Finally, miscellaneous sources generally emit pollutants intermittently, when compared with most stationary point sources. For example, a forest fire may emit large quantities of particulates and carbon monoxide for several hours or even days, but when measured against the emissions of a continuous emitter (such as a sulfuric acid plant) over a long period of time (1 year, for example), its emissions may seem relatively minor. Effects on air quality may also be of relatively short-term duration.

11.1 FOREST WILDFIRES

by William M. Vatavuk, EPA
and George Yamate, IIT (Consultant)

11.1.1 General[1]

A forest "wildfire" is a large-scale natural combustion process that consumes various ages, sizes, and types of botanical specimens growing outdoors in a defined geographical area. Consequently, wildfires are potential sources of large amounts of air pollutants that should be considered when trying to relate emissions to air quality.

The size and intensity (or even the occurrence) of a wildfire is directly dependent on such variables as the local meteorological conditions, the species of trees and their moisture content, and the weight of consumable fuel per acre (fuel loading). Once a fire begins, the dry combustible material (usually small undergrowth and forest floor litter) is consumed first, and if the energy release is large and of sufficient duration, the drying of green, live material occurs with subsequent burning of this material as well as the larger dry material. Under proper environmental and fuel conditions, this process may initiate a chain reaction that results in a widespread conflagration.

The complete combustion of a forest fuel will require a heat flux (temperature gradient), an adequate oxygen supply, and sufficient burning time. The size and quantity of forest fuels, the meteorological conditions, and the topographic features interact to modify and change the burning behavior as the fire spreads; thus, the wildfire will attain different degrees of combustion during its lifetime.

The importance of both fuel type and fuel loading on the fire process cannot be overemphasized. To meet the pressing need for this kind of information, the U.S. Forest Service is developing a country-wide fuel identification system (model) that will provide estimates of fuel loading by tree-size class, in tons per acre. Further, the environmental parameters of wind, slope, and expected moisture changes have been superimposed on this fuel model and incorporated into a National Fire Danger Rating System (NFDR). This system considers five classes of fuel (three dead and two living), the components of which are selected on the basis of combustibility, response to moisture (for the dead fuels), and whether the living fuels are herbaceous (plants) or ligneous (trees).

Most fuel loading figures are based on values for "available fuel" (combustible material that will be consumed in a wildfire under specific weather conditions). Available fuel values must not be confused with corresponding values for either "total fuel" (all the combustible material that would burn under the most severe weather and burning conditions) or "potential fuel" (the larger woody material that remains even after an extremely high intensity wildfire). It must be emphasized, however, that the various methods of fuel identification are of value only when they are related to the existing fuel quantity, the quantity consumed by the fire, and the geographic area and conditions under which the fire occurs.

For the sake of conformity (and convenience), estimated fuel loadings were obtained for the vegetation in the National Forest Regions and the wildlife areas established by the U.S. Forest Service, and are presented in Table 11.1-1. Figure 11.1-1 illustrates these areas and regions.

Table 11.1-1. SUMMARY OF ESTIMATED FUEL CONSUMED BY FOREST FIRES[a]

Area and Region[b]		Estimated average fuel loading	
		MT/hectare	ton/acre
Rocky Mountain group		83	37
Region 1:	Northern	135	60
Region 2:	Rocky Mountain	67	30
Region 3:	Southwestern	22	10
Region 4:	Intermountain	40	8
Pacific group		43	19
Region 5:	California	40	18
Region 6:	Pacific Northwest	135	60
Region 10:	Alaska	36	16
	Coastal	135	60
	Interior	25	11
Southern group		20	9
Region 8:	Southern	20	9
Eastern group		25	11
North Central group		25	11
Region 9:	Conifers	22	10
	Hardwoods	27	12

[a] Reference 1.

[b] See Figure 11.1-1 for regional boundaries.

11.1.2 Emissions and Controls[1]

It has been hypothesized (but not *proven)* that the nature and amounts of air pollutant emissions are directly related to the intensity and direction (relative to the wind) of the wildfire, and indirectly related to the rate at which the fire spreads. The factors that affect the rate of spread are (1) weather (wind velocity, ambient temperature, and relative humidity), (2) fuels (fuel type, fuel bed array, moisture content, and fuel size), and (3) topography (slope and profile). However, logistical problems (such as size of the burning area) and difficulties in safely situating personnel and equipment close to the fire have prevented the collection of any reliable experimental emission data on actual wildfires, so that it is presently impossible to verify or disprove the above-stated hypothesis. Therefore, until such measurements are made, the only available information is that

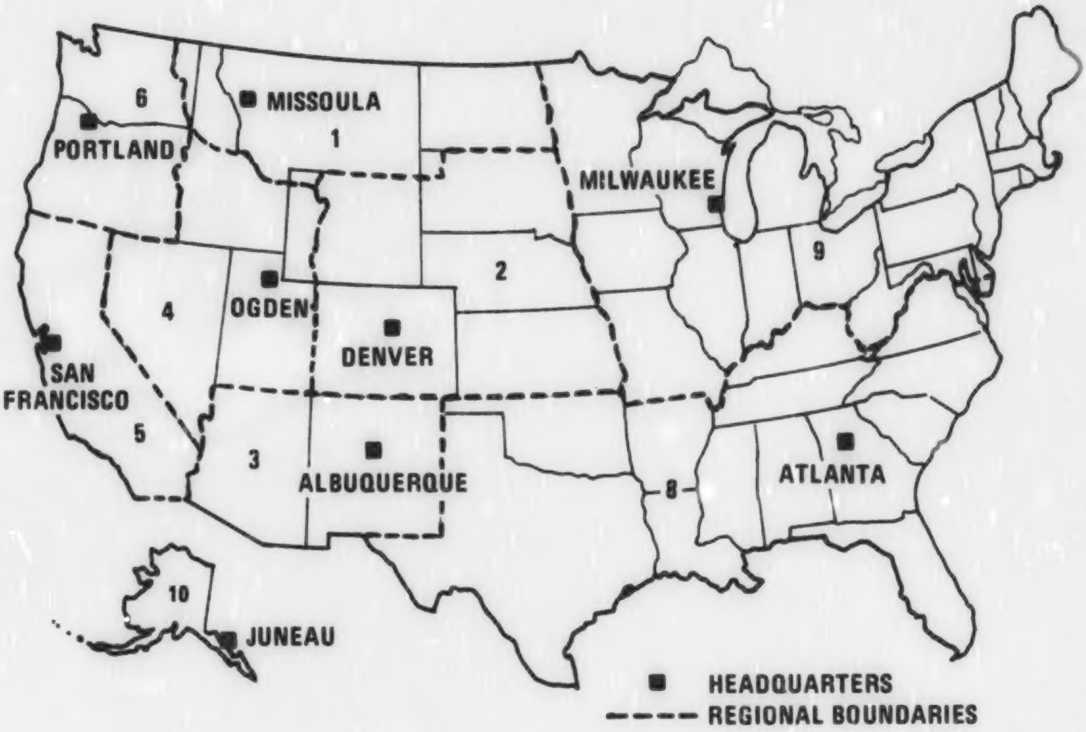
MISSOULA
1
6
PORTLAND
MILWAUKEE
2
9
4
OGDEN
DENVER
SAN FRANCISCO
5
3
ALBUQUERQUE
8
ATLANTA
10
JUNEAU
■ HEADQUARTERS
---- REGIONAL BOUNDARIES

Figure 11.1-1. Forest areas and U.S. Forest Service Regions.

obtained from burning experiments in the laboratory. These data, in the forms of both emissions and emission factors, are contained in Table 11.1-2. It must be emphasized that the factors presented here are adequate for laboratory-scale emissions estimates, but that substantial errors may result if they are used to calculate actual wildfire emissions.

The emissions and emission factors displayed in Table 11.1-2 are calculated using the following formulas:

$$F_i = P_i L \quad (1)$$

$$E_i = F_i A = P_i L A \quad (2)$$

where: F_i = Emission factor (mass of pollutant/unit area of forest consumed)

P_i = Yield for pollutant "i" (mass of pollutant/unit mass of forest fuel consumed)

= 8.5 kg/MT (17 lb/ton) for total particulate

= 70 kg/MT (140 lb/ton) for carbon monoxide

= 12 kg/MT (24 lb/ton) for total hydrocarbon (as CH_4)

Table 11.1-2. SUMMARY OF EMISSIONS AND EMISSION FACTORS FOR FOREST WILDFIRES[a]
EMISSION FACTOR RATING: D

Geographic area[b]	Area consumed by wildfire, hectares	Wildfire fuel consumption, MT/hectare	Emission factors, kg/hectare				Emissions, MT			
			Partic-ulate	Carbon monoxide	Hydro-carbons	Nitrogen oxides	Partic-ulate	Carbon monoxide	Hydro-carbons	Nitrogen oxides
Rocky Mountain group	313,397	83	706	5,810	996	166	220,907	1,819,237	311,869	51,978
Northern, Region 1	142,276	135	1,144	9,420	1,620	269	162,628	1,339,283	229,592	38,265
Rocky Mountain, Region 2	65,882	67	572	4,710	808	135	37,654	310,086	53,157	8,860
Southwestern, Region 3	83,765	22	191	1,570	269	45	15,957	131,417	22,533	3,735
Intermountain, Region 4	21,475	40	153	1,260	215	36	3,273	26,953	4,620	770
Pacific group	469,906	43	362	2,980	512	85	170,090	1,400,738	240,126	40,021
California, Region 5	18,997	40	343	2,830	485	81	6,514	53,645	9,196	1,533
Alaska, Region 10	423,530	36	305	2,510	431	72	129,098	1,063,154	182,255	30,376
Pacific N.W. Region 6	27,380	135	1,144	9,420	1,620	269	31,296	257,738	44,183	7,363
Southern group	806,289	20	172	1,410	242	40	138,244	1,138,484	195,168	32,528
Southern, Region 8	806,289	20	172	1,410	242	40	138,244	1,138,484	195,168	32,528
North Central group	94,191	25	210	1,730	296	49	19,739	162,555	27,867	4,644
Eastern, Region 9 (Both groups are in Region 9)	141,238	25	210	1,730	296	49	29,598	243,746	41,785	6,964
Eastern group (With Region 9)	47,046	25	210	1,730	296	49	9,859	81,191	13,918	2,320
Total United States	1,730,830	38	324	2,670	458	76	560,552	4,616,317	791,369	131,895

[a] Areas consumed by wildfire and emissions are for 1971.

[b] Geographic areas are defined in Figure 11.1-1.

[c] Hydrocarbons expressed as methane.

= 2 kg/MT (4 lb/ton) for nitrogen oxides (NO_x)

= Negligible for sulfur oxides (SO_x)

L = Fuel loading consumed (mass of forest fuel/unit land area burned)

A = Land area burned

E_i = Total emissions of pollutant "i" (mass of pollutant)

For example, suppose that it is necessary to estimate the total particulate emissions from a 10,000 hectare wildfire in the Southern area (Region 8). From Table 11.1-1 it is seen that the average fuel loading is 20 MT/hectare (9 ton/acre). Further, the pollutant yield for particulates is 8.5 kg/MT (17 lb/ton). Therefore, the emissions are:

E = (8.5 kg/MT of fuel) (20 MT of fuel/hectare) (10,000 hectares)

E = 1,700,000 kg = 1,700 MT

The most effective method for controlling wildfire emissions is, of course, to prevent the occurrence of forest fires using various means at the forester's disposal. A frequently used technique for reducing wildfire occurrence is "prescribed" or "hazard reduction" burning. This type of managed burn involves combustion of litter and underbrush in order to prevent fuel buildup on the forest floor and thus reduce the danger of a wildfire. Although some air pollution is generated by this preventative burning, the net amount is believed to be a relatively smaller quantity than that produced under a wildfire situation.

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11.2 FUGITIVE DUST SOURCES

by Charles O. Mann, EPA,
and Chatten C. Cowherd, Jr.,
Midwest Research Institute

Significant sources of atmospheric dust arise from the mechanical disturbance of granular material exposed to the air. Dust generated from these open sources is termed "fugitive" because it is not discharged to the atmosphere in a confined flow stream. Common sources of fugitive dust include: (1) unpaved roads, (2) agricultural tilling operations, (3) aggregate storage piles, and (4) heavy construction operations.

For the above categories of fugitive dust sources, the dust generation process is caused by two basic physical phenomena:

1. Pulverization and abrasion of surface materials by application of mechanical force through implements (wheels, blades, etc.).

2. Entrainment of dust particles by the action of turbulent air currents. Airborne dust may also be generated independently by wind erosion of an exposed surface if the wind speed exceeds about 12 mi/hr (19 km/hr).

The air pollution impact of a fugitive dust source depends on the quantity and drift potential of the dust particles injected into the atmosphere. In addition to large dust particles that settle out near the source (often creating a localized nuisance problem), considerable amounts of fine particles are also emitted and dispersed over much greater distances from the source.

Control techniques for fugitive dust sources generally involve watering, chemical stabilization, or reduction of surface wind speed using windbreaks or source enclosures. Watering, the most common and generally least expensive method, provides only temporary dust control. The use of chemicals to treat exposed surfaces provides longer term dust suppression but may be costly, have adverse impacts on plant and animal life, or contaminate the treated material. Windbreaks and source enclosures are often impractical because of the size of fugitive dust sources. At present, too few data are available to permit estimation of the control efficiencies of these methods.

11.2.1 Unpaved Roads (Dirt and Gravel)

11.2.1.1 General–Dust plumes trailing behind vehicles traveling on unpaved roads are a familiar sight in rural areas of the United States. When a vehicle travels over an unpaved road, the force of the wheels on the road surface cause pulverization of surface material. Particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed.

11.2.1.2 Emissions and Correction Parameters – The quantity of dust emissions from a given segment of unpaved road varies linearly with the volume of traffic. In addition, emissions depend on correction parameters (average vehicle speed, vehicle mix, surface texture, and surface moisture) that characterize the condition of a particular road and the associated vehicular traffic.

In the typical speed range on unpaved roads, that is, 30-50 mi/hr (48-80 km/hr), the results of field measurements indicate that emissions are directly proportional to vehicle speed.[1-3] Limited field measurements further indicate that vehicles produce dust from an unpaved road in proportion to the number of wheels.[1] For roads with a significant volume of vehicles with six or more wheels, the traffic volume should be adjusted to the equivalent volume of four-wheeled vehicles.

Dust emissions from unpaved roads have been found to vary in direct proportion to the fraction of silt (that is, particles smaller than 75 μm in diameter–as defined by American Association of State Highway Officials) in the road surface material.[1] The silt fraction is determined by measuring the proportion of loose, dry, surface dust that passes a 200-mesh screen. The silt content of gravel roads averages about 12 percent, and the silt content of a dirt road may be approximated by the silt content of the parent soil in the area.[1]

Unpaved roads have a hard, nonporous surface that dries quickly after a rainfall. The temporary reduction in emissions because of rainfall may be accounted for by neglecting emissions on "wet" days, that is, days with more than 0.01 in. (0.254 mm) of rainfall.

11.2.1.3 Corrected Emission Factor – The quantity of fugitive dust emissions from an unpaved road, per vehicle-mile of travel, may be estimated (within ± 20 percent) using the following empirical expression[1]:

$$E = \left(0.81\, s\right)\left(\frac{S}{30}\right)\left(\frac{365 - w}{365}\right) \qquad (1)$$

where:
E = Emission factor, pounds per vehicle-mile

s = Silt content of road surface material, percent

S = Average vehicle speed, miles per hour

w = Mean annual number of days with 0.01 in. (0.254 mm) or more of rainfall (see Figure 11.2-1)

The equation is valid for vehicle speeds in the range of 30-50 mi/hr (48-80 km/hr).

On the average, dust emissions from unpaved roads, as given by equation 1, have the following particle size characteristics:[1]

Particle size	Weight percent
$< 30\ \mu m$	60
$> 30\ \mu m$	40

The 30 μm value was determined[1] to be the effective aerodynamic cutoff diameter for the capture of road dust by a standard high-volume filtration sampler, based on a particle density of 2.0-2.5 g/cm^3. On this basis, road dust emissions of particles larger than 30-40 μm in diameter are not likely to be captured by high-volume samplers remote from unpaved roads. Furthermore, the potential drift distance of particles is governed by the initial injection height of the particle, the particle's terminal settling velocity, and the degree of atmospheric turbulence. Theoretical drift distances, as a function of particle diameter and mean wind speed, have been computed for unpaved road emissions.[1] These results indicate that, for a typical mean wind speed of 10 mi/hr (16 km/hr), particles larger than about 100 μm are likely to settle out within 20-30 feet (6-9 m) from the edge of the road. Dust that settles within this distance is not included in equation 1. Particles that are 30-100 μm in diameter are likely to undergo impeded settling. These particles, depending upon the extent of atmospheric turbulence, are likely to settle within a few hundred feet from the road. Smaller particles, particularly those less than 10-15 μm in diameter, have much slower gravitational settling velocities and are much more likely to have their settling rate retarded by atmospheric turbulence. Thus, based on the presently available data, it appears appropriate to report only those particles smaller than 30 μm (60 percent of the emissions predicted by Equation 1) as emissions that may remain indefinitely suspended.

11.2.1.4 Control Methods – Common control techniques for unpaved roads are paving, surface treating with penetration chemicals, working of soil stabilization chemicals into the roadbed, watering, and traffic control regulations. Paving as a control technique is often not practical because of its high cost. Surface chemical treatments and watering can be accomplished with moderate to low costs, but frequent retreatments are required for such techniques to be effective. Traffic controls, such as speed limits and traffic volume restrictions, provide moderate emission reductions, but such regulations may be difficult to enforce. Table 11.2.1-1 shows

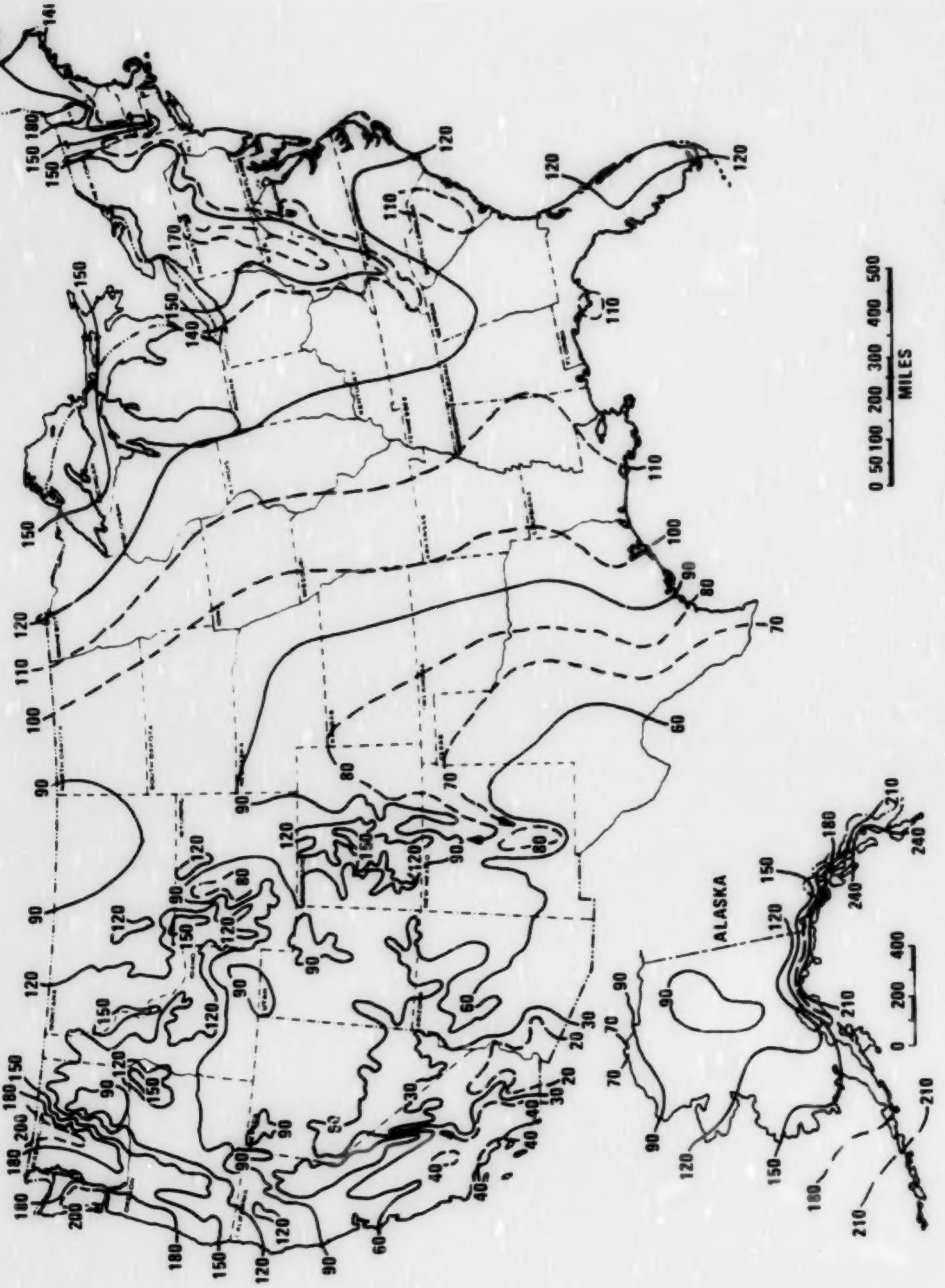
ALASKA
MILES
0 50 100 200 300 400 500
0 200 400
60
70
80
90
100
110
120
140
150
170
180
200
210
240
20
30
40
50

Figure 11.2-1. Mean number of days with 0.01 inch or more of precipitation in United States.4

approximate control efficiencies achievable for each method. Watering, because of the frequency of treatments required, is generally not feasible for public roads and is effectively used only where watering equipment is readily available and roads are confined to a single site, such as a construction location.

Table 11.2.1-1 CONTROL METHODS FOR UNPAVED ROADS

Control method	Approximate control efficiency, %
Paving	85
Treating surface with penetrating chemicals	50
Working soil stabilizing chemicals into roadbed	50
Speed control[a]	
30 mi/hr	25
20 mi/hr	65
15 mi/hr	80

[a] Based on the assumption that "uncontrolled" speed is typically 40 mi/hr. Between 30-50 mi/hr emissions are linearly proportional to vehicle speed. Below 30 mi/hr, however, emissions appear to be proportional to the square of the vehicle speed.[1]

References for Section 11.2.1

1. Cowherd, C., Jr., K. Axetell, Jr., C. M. Guenther, and G. A. Jutze. Development of Emission Factors for Fugitive Dust Sources, Midwest Research Institute, Kansas City, Mo. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. 68-02-0619. Publication No. 450/3-74-037. June 1974.

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11.2.2 Agricultural Tilling

11.2.2.1 General – The two universal objectives of agricultural tilling are the creation of the desired soil structure to be used as the crop seedbed and the eradication of weeds. Plowing, the most common method of tillage, consists of some form of cutting loose, granulating, and inverting the soil and turning under the organic litter. Implements that loosen the soil and cut off the weeds but leave the surface trash in place, have recently become more popular for tilling in dryland farming areas.

During a tilling operation, dust particles from the loosening and pulverization of the soil are injected into the atmosphere as the soil is dropped to the surface. Dust emissions are greatest when the soil is dry and during final seedbed preparation.

11.2.2.2 Emissions and Correction Parameters – The quantity of dust emissions from agricultural tilling is proportional to the area of land tilled. In addition, emissions depend on the following correction parameters, which characterize the condition of a particular field being tilled: (1) surface soil texture, and (2) surface soil moisture content.

Dust emissions from agricultural tilling have been found to vary in direct proportion to the silt content (that is, particles between 2 μm and 50 μm in diameter–as defined by U.S. Department of Agriculture) of the surface soil (0-10 cm depth).[1] The soil silt content is commonly determined by the Buoyocous hydrometer method.[2]

Field measurements indicate that dust emissions from agricultural tilling are inversely proportional to the square of the surface soil moisture (0-10 cm depth).[1] Thornthwaite's precipitation-evaporation (PE) index[3] is a useful approximate measure of average surface soil moisture. The PE index is determined from total annual rainfall and mean annual temperature; rainfall amounts must be corrected for irrigation.

Available test data indicate no substantial dependence of emissions on the type of tillage implement when operating at a typical speed (for example, 8-10 km/hr).[1]

11.2.2.3 Corrected Emission Factor – The quantity of dust emissions from agricultural tilling, per acre of land tilled, may be estimated (within ± 20 percent) using the following empirical expression[1]:

$$E = \frac{1.4s}{\left(\frac{PE}{50}\right)^2} \tag{2}$$

where: E = Emission factor, pounds per acre

s = Silt content of surface soil, percent

PE = Thornthwaite's precipitation-evaporation index (Figure 11.2-2)

Equation 2, which was derived from field measurements, excludes dust that settles out within 20-30 ft (6-9 m) of the tillage path.

On the average, the dust emissions from agricultural tilling, as given by Equation 2, have the following particle size characteristics[1]:

Particle size	*Weight percent*
$< 30\ \mu m$	80
$> 30\ \mu m$	20

The 30 μm value was determined[1] to be the effective aerodynamic cutoff diameter for capture of tillage dust by a standard high-volume filtration sampler, based on a particle density of 2.0-2.5 g/cm^3. As discussed in section 11.2.1.3, only particles smaller than about 30 μm have the potential for long range transport. Thus, for agricultural tilling about 80 percent of the emissions predicted by Equation 2 are likely to remain suspended indefinitely.

11.2.2.4 Control Methods[4] – In general, control methods are not applied to reduce emissions from agricultural tilling. Irrigation of fields prior to plowing will reduce emissions, but in many cases this practice would make the soil unworkable and adversely affect the plowed soil's characteristics. Control methods for agricultural activities are aimed primarily at reduction of emissions from wind erosion through such practices as continuous cropping, stubble mulching, strip cropping, applying limited irrigation to fallow fields, building windbreaks, and using chemical stabilizers. No data are available to indicate the effects of these or other control methods on agricultural tilling, but as a practical matter it may be assumed that emission reductions are not significant.

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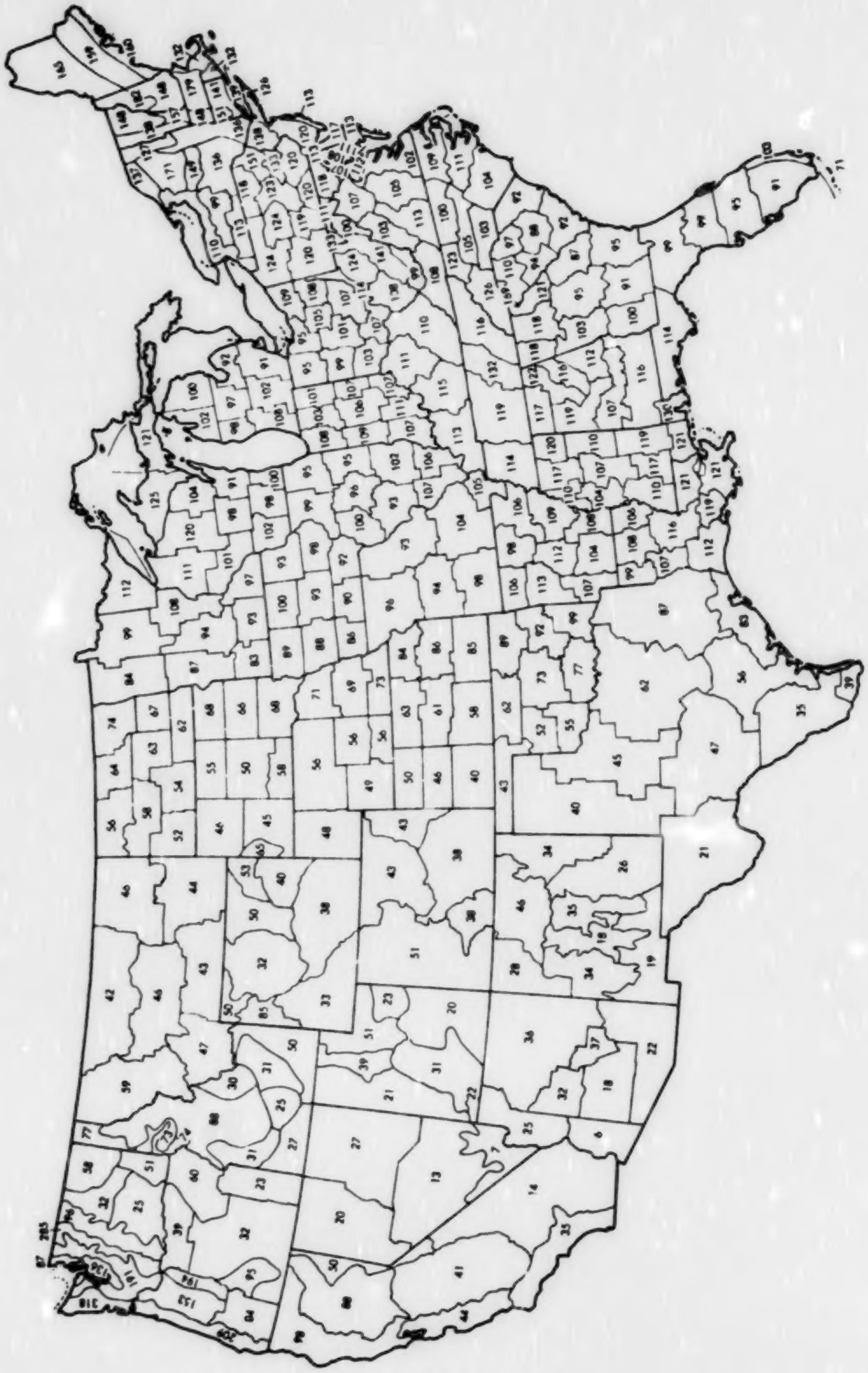

Figure 11.2-2. Map of Thornthwaite's Precipitation-Evaporation Index[3] values for state climatic divisions.

11.2.3 Aggregate Storage Piles

11.2.3.1 General – An inherent part of the operation of plants that utilize minerals in aggregate form is the maintenance of outdoor storage piles. Storage piles are usually left uncovered, partially because of the necessity for frequent transfer of material into or out of storage.

Dust emissions occur at several points in the storage cycle–during loading of material onto the pile, during disturbances by strong wind currents, and during loadout of material from the pile. The movement of trucks and loading equipment in the storage pile area is also a substantial source of dust emissions.

11.2.3.2 Emissions and Correction Parameters – The quantity of dust emissions from aggregate storage operations varies linearly with the volume of aggregate passing through the storage cycle. In addition, emissions depend on the following correction parameters that characterize the condition of a particular storage pile: (1) age of the pile, (2) moisture content, and (3) proportion of aggregate fines.

When freshly processed aggregate is loaded onto a storage pile, its potential for dust emissions is at a maximum. Fines are easily disaggregated and released to the atmosphere upon exposure to air currents resulting from aggregate transfer or high winds. As the aggregate weathers, however, the potential for dust emissions is greatly reduced. Moisture causes aggregation and cementation of fines to the surfaces of larger particles. Any significant rainfall soaks the interior of the pile, and the drying process is very slow.

11.2.3.3 Corrected Emission Factor – Total dust emissions from aggregate storage piles can be divided into the contributions of several distinct source activities that occur within the storage cycle:

1. Loading of aggregate onto storage piles.
2. Equipment traffic in storage area.
3. Wind erosion.
4. Loadout of aggregate for shipment.

Table 11.2.3-1 shows the emissions contribution of each source activity, based on field tests of suspended dust emissions from crushed stone and sand and gravel storage piles.[1] A 3-month storage cycle was assumed in the calculations.

Table 11.2.3-1 AGGREGATE STORAGE EMISSIONS

Source activity	Correction parameter	Approximate percentage of total
Loading onto piles	PE index[a]	12
Vehicular traffic	Rainfall frequency	40
Wind erosion	Climatic factor	33
Loadout from piles	PE index[a]	15
Total		100

[a] Thornthwaite's precipitation-evaporation index.

Also shown in Table 11.2.3-1 are the climatic correction parameters that differentiate the emissions potential of one aggregate storage area from another. Overall, Thornthwaite's precipitation-evaporation index[2] best characterizes the variability of total emissions from aggregate storage piles.

The quantity of suspended dust emissions from aggregate storage piles, per ton of aggregate placed in storage, may be estimated using the following empirical expression[1]:

$$E = \frac{0.33}{\left(\frac{PE}{100}\right)^2} \qquad (3)$$

where: E = Emission factor, pounds per ton placed in storage

PE = Thornthwaite's precipitation-evaporation index (see Figure 11.2-2)

Equation 3 describes the emissions of particles less than 30 μm in diameter. This particle size was determined[1] to be the effective cutoff diameter for the capture of aggregate dust by a standard high-volume filtration sampler, based on a particle density of 2.0-2.5 g/cm^3. Because only particles smaller than 30 μm are included, equation 3 expresses the total emissions likely to remain indefinitely suspended. (See section 11.2.1.3).

11.2.3.4 Control Methods – Watering and use of chemical wetting agents are the principal means for control of aggregate storage pile emissions. Enclosure or covering of inactive piles to reduce wind erosion can also reduce emissions. Watering is useful mainly to reduce emissions from vehicular traffic in the storage pile area. Frequent watering can, based on the breakdowns shown in Table 11.2-3, reduce total emission by about 40 percent. Watering of the storage piles themselves typically has only a very temporary, minimal effect on total emissions. A much more effective technique is to apply chemical wetting agents to provide better wetting of fines and longer retention of the moisture film. Continuous chemical treatment of material loaded onto piles, coupled with watering or treatment of roadways, can reduce total particulate emissions from aggregate storage operations by up to 90 percent.[3]

References for Section 11.2.3

1. Cowherd, C., Jr., K. Axetell, Jr., C. M. Guenther, and G. A. Jutze. Development of Emission Factors for Fugitive Dust Sources. Midwest Research Institute, Kansas City, Mo. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. 68-02-0619. Publication No. EPA-450/3-74-037. June 1974.

2. Thornthwaite, C. W. Climates of North America According to a New Classification. Geograph. Rev. *21*: 633-655, 1931.

3. Jutze, G. A., K. Axetell, Jr., and W. Parker. Investigation of Fugitive Dust-Sources Emissions and Control. PEDCo Environmental Specialists, Inc., Cincinnati, Ohio. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. 68-02-0044. Publication No. EPA-450/3-74-036a. June 1974.

11.2.4 Heavy Construction Operations

11.2.4.1 General – Heavy construction is a source of dust emissions that may have substantial temporary impact on local air quality. Building and road construction are the prevalent construction categories with the highest emissions potential. Emissions during the construction of a building or road are associated with land clearing, blasting, ground excavation, cut and fill operations, and the construction of the particular facility itself. Dust emissions vary substantially from day to day depending on the level of activity, the specific operations, and the prevailing weather. A large portion of the emissions result from equipment traffic over temporary roads at the construction site.

11.2.4.2 Emissions and Correction Parameters – The quantity of dust emissions from construction operations are proportional to the area of land being worked and the level of construction activity. Also, by analogy to the parameter dependence observed for other similar fugitive dust sources,[1] it is probable that emissions from heavy construction operations are directly proportional to the silt content of the soil (that is, particles smaller than 75 μm in diameter) and inversely proportional to the square of the soil moisture, as represented by Thornthwaite's precipitation-evaporation (PE) index.[2]

11.2.4.3 Emission Factor – Based on field measurements of suspended dust emissions from apartment and shopping center construction projects, an approximate emission factor for construction operations is:

1.2 tons per acre of construction per month of activity

This value applies to construction operations with: (1) medium activity level, (2) moderate silt content ($\sim$30 percent), and (3) semiarid climate (PE $\sim$50; see Figure 11.2-2). Test data are not sufficient to derive the specific dependence of dust emissions on correction parameters.

The above emission factor applies to particles less than about 30 μm in diameter, which is the effective cut-off size for the capture of construction dust by a standard high-volume filtration sampler[1], based on a particle density of 2.0-2.5 g/cm^3.

11.2.4.4 Control Methods – Watering is most often selected as a control method because water and necessary equipment are usually available at construction sites. The effectiveness of watering for control depends greatly on the frequency of application. An effective watering program (that is, twice daily watering with complete coverage) is estimated to reduce dust emissions by up to 50 percent.[3] Chemical stabilization is not effective in reducing the large portion of construction emissions caused by equipment traffic or active excavation and cut and fill operations. Chemical stabilizers are useful primarily for application on completed cuts and fills at the construction site. Wind erosion emissions from inactive portions of the construction site can be reduced by about 80 percent in this manner, but this represents a fairly minor reduction in total emissions compared with emissions occurring during a period of high activity.

References for Section 11.2.4

1. Cowherd, C., Jr., K. Axetell, Jr., C. M. Guenther, and G. A. Jutze. Development of Emissions Factors for Fugitive Dust Sources. Midwest Research Institute, Kansas City, Mo. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. 68-02-0619. Publication No. EPA-450/3-74-037. June 1974.

2. Thornthwaite, C. W. Climates of North America According to a New Classification. Geograph. Rev. *21*: 633-655, 1931.

3. Jutze, G. A., K. Axetell, Jr., and W. Parker. Investigation of Fugitive Dust-Sources Emissions and Control. PEDCo Environmental Specialists, Inc., Cincinnati, Ohio. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. 68-02-0044. Publication No. EPA-450/3-74-036a. June 1974.

APPENDIX A

MISCELLANEOUS DATA

Note: Previous editions of *Compilation of Air Pollutant Emission Factors* presented a table entitled Percentage Distribution by Size of Particles from Selected Sources without Control Equipment. Many of the data have become obsolete with the development of new information. As soon as the new information is sufficiently refined, a new table, complete with references, will be published for addition to this document.

Table A-1. NATIONWIDE EMISSIONS FOR 1971 [a]

Pollutant	Stationary combustion		Solid waste disposal		Mobile combustion		Industrial processes		Miscellaneous		Total[b]	
	ton/yr	Mg/yr[c]	ton/yr	Mg/yr	ton/yr	Mg/yr	ton/yr	Mg/yr	ton/yr	Mg/yr	ton/yr	Mg/yr
Particulates	6,500,000	5,900,000	700,000	600,000	1,000,000	900,000	13,500,000	12,200,000	5,200,000	4,800,000	26,900,000	24,400,000
Sulfur oxides	26,300,000	23,900,000	100,000	100,000	1,000,000	1,000,000	5,100,000	4,600,000	100,000	100,000	32,600,000	29,700,000
Carbon monoxide	1,000,000	900,000	3,800,000	3,400,000	77,500,000	70,200,000	11,400,000	10,300,000	6,500,000	5,900,000	100,200,000	90,700,000
Hydrocarbons	300,000	300,000	1,000,000	900,000	14,700,000	13,300,000	5,600,000	5,100,000	5,000,000	4,500,000	26,600,000	24,100,000
Nitrogen oxides	10,200,000	9,300,000	200,000	200,000	11,200,000	10,200,000	200,000	200,000	200,000	200,000	22,000,000	20,100,000

[a] Reference 1.

[b] Some totals may be rounded to a convenient number of figures.

[c] Mg - megagrams.

Table A-2. DISTRIBUTION BY PARTICLE SIZE OF AVERAGE COLLECTION EFFICIENCIES FOR VARIOUS PARTICULATE CONTROL EQUIPMENT[a,b]

Type of collector	Efficiency, %					
		Particle size range, μm				
	Overall	0 to 5	5 to 10	10 to 20	20 to 44	>44
Baffled settling chamber	58.6	7.5	22	43	80	90
Simple cyclone	65.3	12	33	57	82	91
Long-cone cyclone	84.2	40	79	92	95	97
Multiple cyclone (12-in. diameter)	74.2	25	54	74	95	98
Multiple cyclone (6-in. diameter)	93.8	63	95	98	99.5	100
Irrigated long-cone cyclone	91.0	63	93	96	98.5	100
Electrostatic precipitator	97.0	72	94.5	97	99.5	100
Irrigated electrostatic precipitator	99.0	97	99	99.5	100	100
Spray tower	94.5	90	96	98	100	100
Self-induced spray scrubber	93.6	85	96	98	100	100
Disintegrator scrubber	98.5	93	98	99	100	100
Venturi scrubber	99.5	99	99.5	100	100	100
Wet-impingement scrubber	97.9	96	98.5	99	100	100
Baghouse	99.7	99.5	100	100	100	100

[a] References 2 and 3.

[b] Data based on standard silica dust with the following particle size and weight distribution:

Particle size range, μm	Percent by weight
0 to 5	20
5 to 10	10
10 to 20	15
20 to 44	20
> 44	35

Table A-3. THERMAL EQUIVALENTS FOR VARIOUS FUELS

Type of fuel	Btu (gross)	kcal
Solid fuels		
Bituminous coal	(21.0 to 28.0) x 10^6/ton	(5.8 to 7.8) x 10^6/MT
Anthracite coal	25.3 x 10^6/ton	7.03 x 10^6/MT
Lignite	16.0 x 10^6/ton	4.45 x 10^6/MT
Wood	21.0 x 10^6/cord	1.47 x 10^6/m^3
Liquid fuels		
Residual fuel oil	6.3 x 10^6/bbl	10 x 10^3/liter
Distillate fuel oil	5.9 x 10^6/bbl	9.35 x 10^3/liter
Gaseous fuels		
Natural gas	1,050/ft^3	9,350/m^3
Liquefied petroleum gas		
Butane	97,400/gal	6,480/liter
Propane	90,500/gal	6,030/liter

Table A-4. WEIGHTS OF SELECTED SUBSTANCES

Type of substance	lb/gal	g/liter
Asphalt	8.57	1030
Butane, liquid at 60° F	4.84	579
Crude oil	7.08	850
Distillate oil	7.05	845
Gasoline	6.17	739
Propane, liquid at 60° F	4.24	507
Residual oil	7.88	944
Water	8.4	1000

Table A-5. GENERAL CONVERSION FACTORS

Type of substance	Conversion factors
Fuel	
Oil	1 bbl = 42 gal = 159 liters
Natural gas	1 therm = 100,000 Btu = 95 ft^3 1 therm = 25,000 kcal = 2.7 m^3
Agricultural products	
Corn	1 bu = 56 lb = 25.4 kg
Milo	1 bu = 56 lb = 25.4 kg
Oats	1 bu = 32 lb = 14.5 kg
Barley	1 bu = 48 lb = 21.8 kg
Wheat	1 bu = 60 lb = 27.2 kg
Cotton	1 bale = 500 lb = 226 kg
Mineral products	
Brick	1 brick = 6.5 lb = 2.95 kg
Cement	1 bbl = 375 lb = 170 kg
Cement	1 yd^3 = 2500 lb = 1130 kg
Concrete	1 yd^3 = 4000 lb = 1820 kg
Mobile sources	
Gasoline-powered motor vehicle	1.0 mi/gal = 0.426 km/liter
Diesel-powered motor vehicle	1.0 mi/gal = 0.426 km/liter
Steamship	1.0 gal/naut mi = 2.05 liters/km
Motorship	1.0 gal/naut mi = 2.05 liters/km
Other substances	
Paint	1 gal = 10 to 15 lb = 4.5 to 6.82 kg
Varnish	1 gal = 7 lb = 3.18 kg
Whiskey	1 bbl = 50 gal = 188 liters
Water	1 gal = 8.3 lb = 3.81 kg
Miscellaneous factors	1 lb = 7000 grains = 453.6 grams 1 ft^3 = 7.48 gal = 28.32 liters
Metric system	1 ft = 0.3048 m 1 mi = 1609 m 1 lb = 453.6 g 1 ton (short) = 907.2 kg 1 ton (short) = 0.9072 MT (metric ton)

REFERENCES FOR APPENDIX

1. Unpublished data file of nationwide emissions for 1970. Environmental Protection Agency, Office of Air Programs, Research Triangle Park, N.C.

2. Stairmand, C.J. The Design and Performance of Modern Gas Cleaning Equipment. J. Inst. Fuel. *29*:58-80. 1956.

3. Stairmand, C.J. Removal of Grit, Dust, and Fume from Exhaust Gases from Chemical Engineering Processes. London. Chem. Eng. p. 310-326, December 1965.

APPENDIX B

EMISSION FACTORS
AND
NEW SOURCE PERFORMANCE STANDARDS
FOR STATIONARY SOURCES

The New Source Performance Standards (NSPS) promulgated by the Environmental Protection Agency for various industrial categories and the page reference in this publication where uncontrolled emission factors for those sources are discussed are presented in Tables B-1 and B-2. Note that, in the case of steam-electric power plants, the NSPS encompass much broader source categories than the corresponding emission factors. In several instances, the NSPS were formulated on different bases than the emission factors (for example, grains per standard cubic foot versus pounds per ton). Non-criteria pollutant standards have not been included in Table B-2. Finally, note that NSPS relating to opacity have been omitted because they cannot (at this time) be directly correlated with emission factors.

Table B-1. PROMULGATED NEW SOURCE PERFORMANCE STANDARDS

Source category and pollutant	New Source Performance Standard (maximum 2-hr average)	AP-42 page reference
Fossil-fuel-fired steam generators with $>63 \times 10^6$ kcal/hr (250×10^6 Btu/hr) of heat input		
Coal-burning plants (excluding lignite)		
Pulverized wet bottom		
Particulates	0.18 g/10^6 cal heat input (0.10 lb/10^6 Btu)	1.1-3
Sulfur dioxide	2.2 g/10^6 cal heat input (1.2 lb/10^6 Btu)	1.1-3
Nitrogen oxides (as NO_2)	1.26 g/10^6 cal heat input (0.70 lb/10^6 Btu)	1.1-3
Pulverized dry bottom		
Particulates	0.18 g/10^6 cal heat input (0.10 lb/10^6 Btu)	1.1-3
Sulfur dioxide	2.2 g/10^6 cal heat input (1.2 lb/10^6 Btu)	1.1-3
Nitrogen oxides (as NO_2)	1.26 g/10^6 cal heat input (0.70 lb/10^6 Btu)	1.1-3
Pulverized cyclone		
Particulates	0.18 g/10^6 cal heat input (0.10 lb/10^6 Btu)	1.1-3
Sulfur dioxide	2.2 g/10^6 cal heat input (1.2 lb/10^6 Btu)	1.1-3
Nitrogen oxides (as NO_2)	1.26 g/10^6 cal heat input (0.70 lb/10^6 Btu)	1.1-3
Spreader stoker		
Particulates	0.18 g/10^6 cal heat input (0.10 lb/10^6 Btu)	1.1-3
Sulfur dioxide	2.2 g/10^6 cal heat input (1.2 lb/10^6 Btu)	1.1-3
Nitrogen oxides (as NO_2)	1.26 g/10^6 cal heat input (0.70 lb/10^6 Btu)	1.1-3
Residual-oil-burning plants		
Particulates	0.18 g/10^6 cal heat input (0.10 lb/10^6 Btu)	1.3-2
Sulfur dioxide	1.4 g/10^6 cal heat input (0.80 lb/10^6 Btu)	1.3-2
Nitrogen oxides (as NO_2)	0.54 g/10^6 cal heat input (0.30 lb/10^6 Btu)	1.3-2
Natural-gas-burning plants		
Particulates	0.18 g/10^6 cal heat input (0.10 lb/10^6 Btu)	1.4-2
Nitrogen oxides (as NO_2)	0.36 g/106 cal heat input (0.20 lb/10^6 Btu)	1.4-2
Municipal incinerators		
Particulates	0.18 g/Nm^3 (0.08 gr/scf) corrected to 12% CO_2	2.1-1
Portland cement plants		
Kiln–dry process		
Particulates	0.15 kg/MT (0.30 lb/ton) of feed to kiln	8.6-3

Table B-1. (continued). PROMULGATED NEW SOURCE PERFORMANCE STANDARDS

Source category and pollutant	New Source Performance Standard (maximum 2-hr average)	AP-42 page reference
Kiln—wet process Particulates	0.15 kg/MT (0.30 lb/ton) of feed to kiln	8.6-3
Clinker cooler Particulates	0.050 kg/MT (0.10 lb/ton) of feed to kiln	8.6-4
Nitric acid plants Nitrogen oxides (as NO_2)	1.5 kg/MT (3.0 lb/ton) of 100% acid produced	5.9-3
Sulfuric acid plants Sulfur dioxide	2.0 kg/MT (4.0 lb/ton) of 100% acid produced	5.17-5
Sulfuric acid mist (as H_2SO_4)	0.075 kg/MT (0.15 lb/ton) of 100% acid produced	5.17-7

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[a] Title 40 – Protection of Environment. Part 60—Standards of Performance for New Stationary Sources. Federal Register. *36* (247):24876. December 23, 1971

Table B-2. PROMULGATED NEW SOURCE PERFORMANCE STANDARDS

Source category and pollutant	New source performance standard	AP-42 page reference
Asphalt concrete plants[a]		
Particulates	90 mg/Nm^3 (0.040 gr/dscf)	8.1-4
Petroleum refineries		
Fluid catalytic cracking units[a]		
Particulates	60 mg/Nm^3 (0.026 gr/dscf)[b]	
Carbon monoxide	0.050% by volume	9.1-3
Fuel gas combustion	230 mg H_2S/Nm^3	
SO_2	(0.10 gr H_2S/Nm^3	9.1-3
Storage vessels for petroleum liquids[a]		
"Floating roof" storage tanks		
Hydrocarbons	For vapor pressure 78-570 mm Hg, equip with floating roof, vapor recovery system, or equivalent; for vapor pressure > 570 mm Hg, equip with vapor recovery system or equivalent.	4.3-8
Secondary lead smelters[a]		
Blast (cupola) furnaces		
Particulates	50 mg/Nm^3 (0.022 gr/dscf)	7.11-2
Reverberatory furnaces		
Particulates	50 mg/Nm^3 (0.022 gr/dscf)	7.11-2
Secondary brass and bronze ingot production plants[a]		
Reverberatory furnaces		
Particulates	50 mg/Nm^3 (0.022 gr/dscf)	7.9-2
Iron and steel plants[a, f]		
Basic oxygen process furnaces		
Particulates	50 mg/Nm^3 (0.022 gr/dscf)	7.5-5
Electric arc furnaces		
Particulates	12 mg/Nm^3 (0.0052 gr/dscf)	7.5-5
Sewage treatment plants[a]		
Sewage sludge incinerators		
Particulates	0.65 g/kg (1.30 lb/ton) of dry sludge input	2.5-2
Primary copper smelters[c]		
Dryer		
Particulates	50 mg/Nm^3 (0.022 gr/dscf)	7.3-2
Roaster		
Sulfur dioxide	0.065%	7.3-2
Smelting Furnace*		
Sulfur dioxide	0.065%	7.3-2
Copper converter		
Sulfur dioxide	0.065%	7.3-2
*Reverberatory furnaces that process high-impurity feed materials are exempt from sulfur dioxide standard		
Primary lead smelters[c]		
Blast furnace		
Particulates	50 mg/Nm^3 (0.022 gr/dscf)	7.6-4
Reverberatory furnace		
Particulates	50 mg/Nm^3 (0.022 gr/dscf)	7.6-4
Sintering machine discharge end		
Particulates	50 mg/Nm^3 (0.022 gr/dscf)	7.6-4

Table B-2 (continued). PROMULGATED NEW SOURCE PERFORMANCE STANDARDS

Source category and pollutant	New source performance standard	AP-42 page reference
Electric smelting furnace		
Sulfur dioxide	0.065%	7.6-4
Converter		
Sulfur dioxide	0.065%	7.6-4
Sintering machine		
Sulfur dioxide	0.065%	7.6-4
Primary zinc smelters[c]		
Sintering machine		
Particulates	50 mg/Nm^3 (0.022 gr/dscf)	7.7-1
Roaster		
Sulfur dioxide	0.065%	7.7-1
Coal preparation plants[d]		
Thermal dryer		
Particulates	70 mg/Nm^3 (0.031 gr/dscf)	8.9-1
Pneumatic coal cleaning equipment		
Particulates	40 mg/Nm^3 (0.018 gr/dscf)	8.9-1
Ferroalloy production facilities[e]		
Electric submerged arc furnaces		
Particulates	0.45 kg/Mw-hr (0.99 lb/Mw-hr) ("high silicon alloys") 0.23 kg/Mw-hr (0.51 lb/Mw-hr) (chrome and manganese alloys) No visible emissions may escape furnace capture system. No visible emissions may escape tapping system for > 40% of each tapping period.	7.4-2
Carbon monoxide	20% volume basis	7.4-1

[a] Title 40 - Protection of Environment. Part 60 - Standards of Performance for New Stationary Sources: Additions and Miscellaneous Amendments. Federal Register. 39 (47). March 8, 1974.

[b] The actual NSPS reads "1.0 kg/1000 kg (1.0 lb/1000 lb) of coke burn-off in the catalyst regenerator," which is approximately equivalent to an exhaust gas concentration of 60 mg/Nm^3 (0.026 gr/dscf).

[c] Title 40 - Protection of Environment. Part 60 - Standards of Performance for New Stationary Sources: Primary Copper, Zinc, and Lead Smelters. Federal Register. 41. January 15, 1976.

[d] Title 40 - Protection of Environment. Part 60 - Standards of Performance for New Stationary Sources: Coal Preparation Plants. Federal Register. 41. January 15, 1976.

[e] Title 40 - Protection of Environment. Part 60 - Standards of Performance for New Stationary Sources: Ferroalloy Production Facilities. Federal Register. 41. May 4, 1976.

[f] Title 40 - Protection of Environment. Part 60 - Standards of Performance for New Stationary Sources: Electric Arc Furnaces in the Steel Industry. Federal Register. 40. September 23, 1975.

APPENDIX C

NEDS SOURCE CLASSIFICATION CODES AND EMISSION FACTOR LISTING

The Source Classification Codes (SCC's) presented herein comprise the basic "building blocks" upon which the National Emissions Data System (NEDS) is structured. Each SCC represents a process or function within a source category logically associated with a point of air pollution emissions. In NEDS, any operation that causes air pollution can be represented by one or more of these SCC's.

Also presented herein are emission factors for the five NEDS pollutants (particulates, sulfur oxides, nitrogen oxides, hydrocarbons, and carbon monoxide) that correspond to each SCC. These factors are utilized in NEDS to automatically compute estimates of air pollutant emissions associated with a process when a more accurate estimate is not supplied to the system. These factors are, for the most part, taken directly from AP-42. In certain cases, however, they may be derived from better information not yet incorporated into AP-42 or be based merely on the similarity of one process to another for which emissions information does exist.

Because these emission factors are merely single representative values taken, in many cases, from a broad range of possible values and because they do not reflect all of the variables affecting emissions that are described in detail in this document, the user is cautioned not to use the factors listed in Appendix C out of context to estimate the emissions from any given source. Instead, if emission factors must be used to estimate emissions, the appropriate section of this document should be consulted to obtain the most applicable factor for the source in question. The factors presented in Appendix C are reliable only when applied to numerous sources as they are in NEDS.

NOTE: The Source Classification Code and emission factor listing presented in Appendix C was created on October 21, 1975, to replace the listing dated June 20, 1974. The listing has been updated to include several new Source Classification Codes as well as several new or revised emission factors that are considered necessary for the improvement of NEDS. The listing will be updated periodically as better source and emission factor information becomes available. Any comments regarding this listing, especially those pertaining to the need for additional SCC's, should be directed to:

Chief, Emission Factor Section (MD-14)
National Air Data Branch
Environmental Protection Agency
Research Triangle Park, N.C. 27711

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FILE CREATED ON 10/21/75          N A T I O N A L  E M I S S I O N  D A T A  S Y S T E M
                                    S O U R C E  C L A S S I F I C A T I O N  C O D E S

                                      P O U N D S  E M I T T E D  P E R  U N I T
                                       PART        SOX          NOX          HC          CO       U N I T S
EXTCOMB BOILER    -ELECTRIC GENERATN
***************** *****************

   ANTHRACITE COAL

      1-01-001-01  >100MMBTU PULVIZD     17.0  A     38.0  S     18.0         0.03         1.00  TONS BURNED
      1-01-001-02  >100MMBTU STOKERS      2.00 A     38.0  S     10.5         0.20         6.00  TONS BURNED
      1-01-001-03  10-100MMBTU PULVD     17.0  A     38.0  S     18.0         0.03         1.00  TONS BURNED
      1-01-001-04  10-100MMBTU STOKR      2.00 A     38.0  S     10.5         0.20         6.00  TONS BURNED
      1-01-001-05  <10MMBTU PULVIZED     17.0  A     38.0  S     18.0         0.03         1.00  TONS BURNED
      1-01-001-06  <10MMBTU STOKER        2.00 A     38.0  S      6.00        0.20        10.0   TONS BURNED
      1-01-001-99  OTHER/NOT CLASIFD     17.0  A     38.0  S     18.0         0.03         1.00  TONS BURNED

   BITUMINOUS COAL

      1-01-002-01  >100MMBTU PULVWET     13.0  A     38.0  S     30.0         0.30         1.00  TONS BURNED
      1-01-002-02  >100MMBTU PULVDRY     17.0  A     38.0  S     18.0         0.30         1.00  TONS BURNED
      1-01-002-03  >100MMBTU CYCLONE      2.00 A     38.0  S     55.0         0.30         1.00  TONS BURNED
      1-01-002-04  >100MMBTU SPDSTKR     13.0  A     38.0  S     15.0         1.00         2.00  TONS BURNED
      1-01-002-05  >100MMBTU/HR OFSK      5.00 A     38.0  S     15.0         1.00         2.00  TONS BURNED
      1-01-002-06  10-100MMBTU PULWT     13.0  A     38.0  S     30.0         0.30         1.00  TONS BURNED
      1-01-002-07  10-100MMBTU PULDY     17.0  A     38.0  S     18.0         0.30         1.00  TONS BURNED
      1-01-002-08  10-100MMBTU OFSTK      5.00 A     38.0  S     15.0         1.00         2.00  TONS BURNED
      1-01-002-09  10-100MMBTU UFSTK      5.00 A     38.0  S     15.0         1.00         2.00  TONS BURNED
      1-01-002-10  <10MMBTU OFSTOKER      7.00 A     38.0  S      6.00        3.00        10.0   TONS BURNED
      1-01-002-11  <10MMBTU UFSTOKER      7.00 A     38.0  S      6.00        3.00        10.0   TONS BURNED
      1-01-002-12  <10MMBTU PULV-DRY     17.0  A     38.0  S     18.0         0.30         1.00  TONS BURNED
      1-01-002-99  OTHER/NOT CLASIFD     16.0  A     38.0  S     18.0         0.30         0.50  TONS BURNED

   LIGNITE

      1-01-003-01  >100MMBTU PULVWET      6.50 A     30.0  S     13.0         0.30         1.00  TONS BURNED
      1-01-003-02  >100MMBTU PULVDRY      6.50 A     30.0  S     13.0         0.30         1.00  TONS BURNED
      1-01-003-03  >100MMBTU CYCLONE      6.50 A     30.0  S     17.0         0.30         1.00  TONS BURNED
      1-01-003-04  >100MMBTU OF STKR      6.50 A     30.0  S     13.0         0.30         2.00  TONS BURNED
      1-01-003-05  >100MMBTU UF STKR      6.50 A     30.0  S     13.0         0.30         2.00  TONS BURNED
      1-01-003-06  >100MMBTU SPDSTKR      6.50 A     30.0  S     13.0         0.30         2.00  TONS BURNED
      1-01-003-07  10-100MMBTU DYPUL      6.50 A     30.0  S     13.0         0.30         1.00  TONS BURNED
      1-01-003-08  10-100MMBTU WTPUL      6.50 A     30.0  S     13.0         0.30         1.00  TONS BURNED
      1-01-003-09  10-100MMBTU OFSTK      6.50 A     30.0  S     13.0         1.00         2.00  TONS BURNED
      1-01-003-10  10-100MMBTU UFSTK      6.50 A     30.0  S     13.0         1.00         2.00  TONS BURNED
      1-01-003-11  10-100MMBTUSPDSTK      6.50 A     30.0  S     13.0         1.00         2.00  TONS BURNED
      1-01-003-12  <10MMBTU PULV DRY      6.50 A     30.0  S     13.0         3.00        10.0   TONS BURNED
      1-01-003-13  <10MMBTU OF STOKR      6.50 A     30.0  S     13.0         3.00        10.0   TONS BURNED
      1-01-003-14  <10MMBTU UF STOKR      6.50 A     30.0  S     13.0         3.00        10.0   TONS BURNED
      1-01-003-15  <10MMBTU SPDSTOKR      6.50 A     30.0  S     13.0         3.00        10.0   TONS BURNED

   RESIDUAL OIL

      1-01-004-01  >100MMBTU/HR GENL      8.00      157.   S    105.          2.00         3.00  1000GALLONS BURNED
      1-01-004-02  10-100MMBTU/HRGNL      8.00      157.   S    105.          2.00         3.00  1000GALLONS BURNED
      1-01-004-03  <10MMBTU/HR GENL       8.00      157.   S    105.          2.00         3.00  1000GALLONS BURNED

   DISTILLATE OIL

      1-01-005-01  >100MMBTU/HR GENL      8.00      144.   S    105.          2.00         3.00  1000GALLONS BURNED
      1-01-005-02  10-100MMBTU/HRGNL      8.00      144.   S    105.          2.00         3.00  1000GALLONS BURNED
      1-01-005-03  <10MMBTU/HR GENL       8.00      144.   S    105.          2.00         3.00  1000GALLONS BURNED

   NATURAL GAS

      1-01-006-01  >100MMBTU/HR          10.0         0.60      600.          1.00        17.0   MILLION CUBIC FEET BURNED
      1-01-006-02  10-100MMBTU/HR        10.0         0.60      230.          1.00        17.0   MILLION CUBIC FEET BURNED
      1-01-006-03  <10MMBTU/HR           10.0         0.60      120.          1.00        17.0   MILLION CUBIC FEET BURNED

   PROCESS GAS

      1-01-007-01  >100MMBTU/HR          15.0       950.   S    600.          1.00        17.0   MILLION CUBIC FEET BURNED
      1-01-007-02  10-100MMBTU/HR        15.0       950.   S    230.          1.00        17.0   MILLION CUBIC FEET BURNED
      1-01-007-03  <10 MMBTU/HR          15.0       950.   S    120.          1.00        17.0   MILLION CUBIC FEET BURNED

   COKE

      1-01-008-01  >100MMBTU/HR          17.0  A     38.0  S     18.0         0.03         1.00  TONS BURNED

   WOOD/BARK WASTE

      1-01-009-01  BARK BOILER           75.0          1.50      10.0         2.00         2.00  TONS BURNED
      1-01-009-02  WOOD/BARK BOILER      37.5          1.50      10.0         2.00         2.00  TONS BURNED
      1-01-009-03  WOOD BOILER           10.0          1.50      10.0         5.00        10.0   TONS BURNED

   BAGASSE

      1-01-011-01  >100MMBTU/HR          22.0          0.         2.00        2.00         2.00  TONS BURNED
      1-01-011-02  10-100MMBTU/HR        22.0          0.         2.00        2.00         2.00  TONS BURNED
      1-01-011-03  <10MMBTU/HR           22.0          0.         2.00        2.00         2.00  TONS BURNED

   SLD WASTE-SPECIFY

      1-01-012-01  >100 MMBTU/HR                                                               TONS BURNED
      1-01-012-02  10-100 MMBTU/HR                                                             TONS BURNED
      1-01-012-03  <10 MMBTU/HR                                                                TONS BURNED
'A' INDICATES THE ASH CONTENT, 'S' INDICATES THE SULFUR CONTENT OF THE FUEL ON A PERCENT BASIS (BY WEIGHT)
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                                      NATIONAL EMISSION DATA SYSTEM
                                       SOURCE CLASSIFICATION CODES

                                         POUNDS EMITTED PER UNIT
                                       PART        SOX          NOX          HC           CO        UNITS
EXCOMB BOILER     -ELECTRIC GENERATN
*****************  *****************

   LIQ WASTE-SPECIFY

      1-01-013-01  >100 MMBTU/HR                                                                 1000 GALLONS BURNED
      1-01-013-02  10-100 MMBTU/HR                                                               1000 GALLONS BURNED
      1-01-013-03  <10 MMBTU/HR                                                                  1000 GALLONS BURNED

   OTHER/NOT CLASIFD

      1-01-999-97  SPECIFY IN REMARK                                                             MILLION CUBIC FEET BURNED
      1-01-999-98  SPECIFY IN REMARK                                                             1000 GALLON (LIQUID) BURNED
      1-01-999-99  SPECIFY IN REMARK                                                             TONS BURNED (SOLID)

EXTCOMB BOILER    -INDUSTRIAL
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   ANTHRACITE COAL

      1-02-001-01  >100MMBTU/HR PULV     17.0  A     38.0  S     18.0         0.03         1.00  TONS BURNED
      1-02-001-02  >100MMBTU/HR STKR      2.00 A     38.0  S     10.5         0.20         6.00  TONS BURNED
      1-02-001-03  10-100MMBTU PULVD     17.0  A     38.0  S     18.0         0.03         1.00  TONS BURNED
      1-02-001-04  10-100MMBTU STKR       2.00 A     38.0  S     10.5         0.20         6.00  TONS BURNED
      1-02-001-05  <10MMBTU/HR PULVD     17.0  A     38.0  S     18.0         0.03         1.00  TONS BURNED
      1-02-001-06  <10MMBTU/HR STKR       2.00 A     38.0  S      6.00        0.20        10.0   TONS BURNED
      1-02-001-07  <10MMBTU/HR HNDFR     10.0        36.0  S      3.00        2.50        90.0   TONS BURNED
      1-02-001-99  OTHER/NOT CLASIFD     17.0  A     38.0  S     18.0         0.03         2.00  TONS BURNED

   BITUMINOUS COAL

      1-02-002-01  >100MMBTU PULVWET     13.0  A     38.0  S     30.0         0.30         1.00  TONS BURNED
      1-02-002-02  >100MMBTU PULVDRY     17.0  A     38.0  S     18.0         0.30         1.00  TONS BURNED
      1-02-002-03  >100MMBTU CYCLONE      2.00 A     38.0  S     55.0         0.30         1.00  TONS BURNED
      1-02-002-04  >100MMBTU SPDSTKR     13.0  A     38.0  S     15.0         1.00         2.00  TONS BURNED
      1-02-002-05  10-100MMBTU OFSTK      5.00 A     38.0  S     15.0         1.00         2.00  TONS BURNED
      1-02-002-06  10-100MMBTU UFSTK      5.00 A     38.0  S     15.0         1.00         2.00  TONS BURNED
      1-02-002-07  10-100MMBTU PULWT     13.0  A     38.0  S     30.0         0.30         1.00  TONS BURNED
      1-02-002-08  10-100MMBTU PULDY     17.0  A     38.0  S     18.0         0.30         1.00  TONS BURNED
      1-02-002-09  10-100MMBTUSPDSTK     13.0  A     38.0  S     15.0         1.00         2.00  TONS BURNED
      1-02-002-10  <10MMBTU OFD STKR      2.00 A     38.0  S      6.00        3.00        10.0   TONS BURNED
      1-02-002-11  <10MMBTU UFD STKR      2.00 A     38.0  S      6.00        3.00        10.0   TONS BURNED
      1-02-002-12  <10MMBTU PULV DRY     17.0  A     38.0  S     18.0         0.30         2.00  TONS BURNED
      1-02-002-13  <10MMBTU SPD STKR      2.00 A     38.0  S      6.00        3.00        10.0   TONS BURNED
      1-02-002-14  <10MMBTU HANDFIRE     20.0        38.0  S      3.00       20.0         90.0   TONS BURNED
      1-02-002-99  OTHER/NOT CLASIFD     13.0  A     38.0  S     15.0         0.30         2.00  TONS BURNED

   LIGNITE

      1-02-003-01  >100MMBTU PULVWET      6.50 A     30.0  S     13.0         0.30         1.00  TONS BURNED
      1-02-003-02  >100MMBTU PULVDRY      6.50 A     30.0  S     13.0         0.30         1.00  TONS BURNED
      1-02-003-03  >100MMBTU CYCLONE      6.50 A     30.0  S     17.0         0.30         1.00  TONS BURNED
      1-02-003-04  >100MMBTU OFSTKR       6.50 A     30.0  S     13.0         1.00         2.00  TONS BURNED
      1-02-003-05  >100MMBTU UFSTKR       6.50 A     30.0  S     13.0         1.00         2.00  TONS BURNED
      1-02-003-06  >100MMBTU SPDSTKR      6.50 A     30.0  S     13.0         1.00         2.00  TONS BURNED
      1-02-003-07  10-100MMBTU DYPUL      6.50 A     30.0  S     13.0         0.30         1.00  TONS BURNED
      1-02-003-08  10-100MMBTU WTPUL      6.50 A     30.0  S     13.0         0.30         1.00  TONS BURNED
      1-02-003-09  10-100MMBTU OFSTK      6.50 A     30.0  S     13.0         1.00         2.00  TONS BURNED
      1-02-003-10  10-100MMBTU UFSTK      6.50 A     30.0  S     13.0         1.00         2.00  TONS BURNED
      1-02-003-11  10-100MMBTUSPDSTK      6.50 A     30.0  S     13.0         1.00         2.00  TONS BURNED
      1-02-003-12  <10MMBTU PULV DRY      6.50 A     30.0  S     13.0         3.00        10.0   TONS BURNED
      1-02-003-13  <10MMBTU OFSTOKR       6.50 A     30.0  S     13.0         3.00        10.0   TONS BURNED
      1-02-003-14  <10MMBTU UFSTOKR       6.50 A     30.0  S     13.0         3.00        10.0   TONS BURNED
      1-02-003-15  <10MMBTU HANDFIRE      6.50 A     30.0  S     13.0        20.0         90.0   TONS BURNED
      1-02-003-16  <10MMBTU SPDSTKR       6.50 A     30.0  S     13.0         3.00        10.0   TONS BURNED

   RESIDUAL OIL

      1-02-004-01  >100MMBTU/HR          23.0        157.  S     60.0         3.00         4.00  1000 GALLONS BURNED
      1-02-004-02  10-100MMBTU/HR        23.0        157.  S     60.0         3.00         4.00  1000 GALLONS BURNED
      1-02-004-03  <10MMBTU/HR           23.0        157.  S     60.0         3.00         4.00  1000 GALLONS BURNED

   DISTILLATE OIL

      1-02-005-01  >100MMBTU/HR          15.0        142.  S     60.0         3.00         4.00  1000 GALLONS BURNED
      1-02-005-02  10-100MMBTU/HR        15.0        142.  S     60.0         3.00         4.00  1000 GALLONS BURNED
      1-02-005-03  <10MMBTU/HR           15.0        142.  S     60.0         3.00         4.00  1000 GALLONS BURNED

   NATURAL GAS

      1-02-006-01  >100MMBTU/HR          10.0          0.60     600.          3.00        17.0   MILLION CUBIC FEET BURNED
      1-02-006-02  10-100MMBTU/HR        10.0          0.60     230.          3.00        17.0   MILLION CUBIC FEET BURNED
      1-02-006-03  <10MMBTU/HR           10.0          0.60     120.          3.00        17.0   MILLION CUBIC FEET BURNED

   PROCESS GAS

      1-02-007-01  REFINERY  >100                                                                MILLION CUBIC FEET BURNED
      1-02-007-02  REFINERY  10-100                                                              MILLION CUBIC FEET BURNED
      1-02-007-03  REFINERY  <10                                                                 MILLION CUBIC FEET BURNED
      1-02-007-04  BLAST FNC >100                                                                MILLION CUBIC FEET BURNED
      1-02-007-05  BLAST FNC 10-100                                                              MILLION CUBIC FEET BURNED
      1-02-007-06  BLAST FNC <10                                                                 MILLION CUBIC FEET BURNED
"A" INDICATES THE ASH CONTENT, "S" INDICATES THE SULFUR CONTENT OF THE FUEL ON A PERCENT BASIS (BY WEIGHT)
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                                    NATIONAL EMISSION DATA SYSTEM
                                    SOURCE CLASSIFICATION CODES

                                     POUNDS EMITTED PER UNIT
                                     PART        SOX        NOX        HC         CO        UNITS
EXTCOMB BOILER     -INDUSTRIAL
****************   ****************

  PROCESS GAS        CONTINUED

     1-02-007-07  COKE OVEN >100                                                           MILLION CUBIC FEET BURNED
     1-02-007-08  COKE OVEN 10-100                                                         MILLION CUBIC FEET BURNED
     1-02-007-09  COKE OVEN <10                                                            MILLION CUBIC FEET BURNED
     1-02-007-99  OTHER/NOT CLASIFD                                                        MILLION CUBIC FEET BURNED

  COKE

     1-02-008-02  10-100MMBTU/HR         2.00 A     38.0  S    15.0       0.20       2.00  TONS BURNED
     1-02-008-03  <10MMBTU/HR            2.00 A     38.0  S     6.00      0.20      10.0   TONS BURNED

  WOOD/BARK WASTE

     1-02-009-01  BARK BOILER           75.0         1.50      10.0       2.00       2.00  TONS BURNED
     1-02-009-02  WOOD/BARK BOILER      37.5         1.50      10.0       2.00       2.00  TONS BURNED
     1-02-009-03  WOOD BOILER           10.0         1.50      10.0       5.00      10.0   TONS BURNED

  LIQ PETROLEUM GAS

     1-02-010-02  10-100MMBTU/HR         1.75       86.5  S    11.7       0.30       1.55  1000GALLONS BURNED
     1-02-010-03  <10MMBTU/HR            1.75       86.5  S    11.7       0.30       1.55  1000GALLONS BURNED

  BAGASSE

     1-02-011-01  >100 MMBTU/HR         22.0          0.        2.00      2.00       2.00  TONS BURNED
     1-02-011-02  10-100MMBTU/HR        22.0          0.        2.00      2.00       2.00  TONS BURNED
     1-02-011-03  <10MMBTU/HR           22.0          0.        2.00      2.00       2.00  TONS BURNED

  SLD WASTE-SPECIFY

     1-02-012-01  >100 MMBTU/HR                                                            TONS BURNED
     1-02-012-02  100-100 MMBTU/HR                                                         TONS BURNED
     1-02-012-03  <10 MMBTU/HR                                                             TONS BURNED

  LIQ WASTE-SPECIFY

     1-02-013-01  >100 MMBTU/HR                                                            1000 GALLONS BURNED
     1-02-013-02  10-100 MMBTU/HR                                                          1000 GALLONS BURNED
     1-02-013-03  <10 MMBTU/HR                                                             1000 GALLONS BURNED

  OTHER/NOT CLASIFD

     1-02-999-97  SPECIFY IN REMARK                                                        MILLION CUBIC FEET BURNED
     1-02-999-98  SPECIFY IN REMARK                                                        1000 GALLON BURNED (LIQUID)
     1-02-999-99  SPECIFY IN REMARK                                                        TONS BURNED (SOLID)

EXTCOMB BOILER     -COMMERCL-INSTUTNL
****************   ****************


  ANTHRACITE COAL

     1-03-001-05  10-100MMBTU PULWT     13.0  A     38.0  S    30.0       0.03       1.00  TONS BURNED
     1-03-001-06  10-100MMBTU PULDY     17.0  A     38.0  S    18.0       0.03       1.00  TONS BURNED
     1-03-001-07  10-100MMBTUSPDSTK     13.0  A     38.0  S    15.0       1.00       2.00  TONS BURNED
     1-03-001-08  <10MMBTU PULVIZED     17.0  A     38.0  S    18.0       0.03       1.00  TONS BURNED
     1-03-001-09  <10MMBTU STOKER        2.00 A     38.0  S     6.00      0.20      10.0   TONS BURNED
     1-03-001-10  <10MMBTU SPDSTOKR      2.00 A     38.0  S    15.0       1.00      10.0   TONS BURNED
     1-03-001-99  OTHER/NOT CLASIFD     17.0  A     38.0  S    18.0       0.03       1.00  TONS BURNED

  BITUMINOUS COAL

     1-03-002-05  10-100MMBTU PULWT     13.0  A     38.0  S    30.0       0.03       1.00  TONS BURNED
     1-03-002-06  10-100MMBTU PULDY     17.0  A     38.0  S    18.0       0.03       1.00  TONS BURNED
     1-03-002-07  10-100MMBTU OFSTK      5.00 A     38.0  S    15.0       1.00       2.00  TONS BURNED
     1-03-002-08  10-100MMBTU UFSTK      5.00 A     38.0  S    15.0       1.00       2.00  TONS BURNED
     1-03-002-09  10-100MMBTUSPDSTK     13.0  A     38.0  S    15.0       1.00       2.00  TONS BURNED
     1-03-002-10  10-100MMBTU HANFR     20.0        38.0  S     3.00     20.0       90.0   TONS BURNED
     1-03-002-11  <10MMBTU OFSTOKER      2.00 A     38.0  S     6.00      3.00      10.0   TONS BURNED
     1-03-002-12  <10MMBTU UFSTOKER      2.00 A     38.0  S     6.00      3.00      10.0   TONS BURNED
     1-03-002-13  <10MMBTU SPDSTOKR      2.00 A     38.0  S     6.00      3.00      10.0   TONS BURNED
     1-03-002-14  <10MMBTU HANDFIRE     20.0        38.0  S     3.00     20.0       90.0   TONS BURNED
     1-03-002-99  OTHER/NOT CLASIFD     13.0  A     38.0  S    15.0       0.30       2.00  TONS BURNED

  LIGNITE

     1-03-003-05  10-100MMBTU PULWT      6.50 A     30.0  S    13.0       1.00       2.00  TONS BURNED
     1-03-003-06  10-100MMBTU PULDY      6.50 A     30.0  S    13.0       1.00       2.00  TONS BURNED
     1-03-003-07  10-100MMBTU OFSTK      6.50 A     30.0  S    13.0       1.00       2.00  TONS BURNED
     1-03-003-08  10-100MMBTU UFSTK      6.50 A     30.0  S    13.0       1.00       2.00  TONS BURNED
     1-03-003-09  10-100MMBTUSPDSTK      6.50 A     30.0  S    13.0       1.00       2.00  TONS BURNED
     1-03-003-10  <10MMBTU PULV-DRY      6.50 A     30.0  S    13.0       1.00      10.0   TONS BURNED
     1-03-003-11  <10MMBTU OFSTOKER      6.50 A     30.0  S    13.0       3.00      10.0   TONS BURNED
     1-03-003-12  <10MMBTU UFSTOKER      6.50 A     30.0  S    13.0       3.00      10.0   TONS BURNED
     1-03-003-13  <10MMBTU SPDSTOKR      6.50 A     30.0  S    13.0       3.00      10.0   TONS BURNED
     1-03-003-14  <10MMBTU HANDFIRE      6.50 A     30.0  S    13.0      20.0       90.0   TONS BURNED

'A' INDICATES THE ASH CONTENT, 'S' INDICATES THE SULFUR CONTENT OF THE FUEL ON A PERCENT BASIS (BY WEIGHT)
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NATIONAL EMISSION DATA SYSTEM
SOURCE CLASSIFICATION CODES

POUNDS EMITTED PER UNIT

EXTCOMB BOILER ****************	-COMMERCL-INSTUTNL ****************	PART	SOX	NOX	HC	CO	UNITS
RESIDUAL OIL							
1-03-004-01	>100MMBTU/HR	23.0	157. S	60.0	3.00	4.00	1000 GALLONS BURNED
1-03-004-02	10-100MMBTU/HR	23.0	157. S	60.0	3.00	4.00	1000 GALLONS BURNED
1-03-004-03	<10MMBTU/HR	23.0	157. S	60.0	3.00	4.00	1000 GALLONS BURNED
DISTILLATE							
1-03-005-01	>100MMBTU/HR	15.0	142. S	60.0	3.00	4.00	1000 GALLONS BURNED
1-03-005-02	10-100MMBTU/HR	15.0	142. S	60.0	3.00	4.00	1000 GALLONS BURNED
1-03-005-03	<10MMBTU/HR	15.0	142. S	60.0	3.00	4.00	1000 GALLONS BURNED
NATURAL GAS							
1-03-006-01	>100MMBTU/HR	10.0	0.60	230.	8.00	20.0	MILLION CUBIC FEET BURNED
1-03-006-02	10-100MMBTU/HR	10.0	0.60	120.	8.00	20.0	MILLION CUBIC FEET BURNED
1-03-006-03	<10MMBTU/HR	10.0	0.60	80.0	8.00	20.0	MILLION CUBIC FEET BURNED
PROCESS GAS							
1-03-007-01	SEWAGE>100MMBTUHR						MILLION CUBIC FEET BURNED
1-03-007-02	SEWAGE 10-100						MILLION CUBIC FEET BURNED
1-03-007-03	SEWAGE<10MMBTU/HR						MILLION CUBIC FEET BURNED
1-03-007-99	OTHER/NOT CLASIFD						MILLION CUBIC FEET BURNED
WOOD/BARK WASTE							
1-03-009-01	BARK BOILER	75.0	1.50	10.0	2.00	2.00	TONS BURNED
1-03-009-02	WOOD/BARK BOILER	37.5	1.50	10.0	2.00	2.00	TONS BURNED
1-03-009-03	WOOD BOILER	10.0	1.50	10.0	5.00	10.0	TONS BURNED
LIQ PETROLEUM GAS							
1-03-010-02	10-100MMBTU/HR	1.85	86.5 S	9.50	0.75	1.95	1000 GALLONS BURNED
1-03-010-03	<10MMBTU/HR	1.85	86.5 S	9.50	0.75	1.95	1000 GALLONS BURNED
SLD WASTE-SPECIFY							
1-03-012-01	>100 MMBTU/HR						TONS BURNED
1-03-012-02	10-100 MMBTU/HR						TONS BURNED
1-03-012-03	<10 MMBTU/HR						TONS BURNED
LIQ WASTE-SPECIFY							
1-03-013-01	>100 MMBTU/HR						1000 GALLONS BURNED
1-03-013-02	10-100 MMBTU/HR						1000 GALLONS BURNED
1-03-013-03	<10 MMBTU/HR						1000 GALLONS BURNED
OTHER/NOT CLASIFD							
1-03-999-97	SPECIFY IN REMARK						MILLION CUBIC FEET BURNED
1-03-999-98	SPECIFY IN REMARK						1000 GALLON BURNED (LIQUID)
1-03-999-99	SPECIFY IN REMARK						TONS BURNED (SOLID)
EXTCOMB BOILER ****************	-SPACE HEATER ****************						
INDUSTRIAL							
1-05-001-01	ANTHRACITE COAL						TONS BURNED
1-05-001-02	BITUMINOUS COAL						TONS BURNED
1-05-001-03	LIGNITE						TONS BURNED
1-05-001-04	RESIDUAL OIL						1000 GALLONS BURNED
1-05-001-05	DISTILLATE OIL						1000 GALLONS BURNED
1-05-001-06	NATURAL GAS						MILLION CUBIC FEET BURNED
1-05-001-10	LIQ PETROLEUM GAS						1000 GALLONS BURNED
1-05-001-97	OTHER-SPECIFY						TONS BURNED
1-05-001-98	OTHER-SPECIFY						1000 GALLONS BURNED
1-05-001-99	OTHER-SPECIFY						MILLION CUBIC FEET BURNED
COMMERCL-INSTUTN							
1-05-002-01	ANTHRACITE COAL						TONS BURNED
1-05-002-02	BITUMINOUS COAL						TONS BURNED
1-05-002-03	LIGNITE						TONS BURNED
1-05-002-04	RESIDUAL OIL						1000 GALLONS BURNED
1-05-002-05	DISTILLATE OIL						1000 GALLONS BURNED
1-05-002-06	NATURAL GAS						MILLION CUBIC FEET BURNED
1-05-002-10	LIQ PETROLEUM GAS						1000 GALLONS BURNED
1-05-002-97	OTHER-SPECIFY						TONS BURNED
1-05-002-98	OTHER-SPECIFY						1000 GALLONS BURNED
1-05-002-99	OTHER-SPECIFY						MILLION CUBIC FEET BURNED

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                                        NATIONAL EMISSION DATA SYSTEM
                                         SOURCE CLASSIFICATION CODES

                                          POUNDS EMITTED PER UNIT
                                        PART       SOX          NOX          HC          CO          UNITS
INTERNLCOMBUSTION -ELECTRIC GENERATN
*****************  *****************

   DISTILLATE OIL

      2-01-001-01  TURBINE             5.00      140.   S     67.8         5.57        15.4    1000 GALLONS BURNED
      2-01-001-02  RECIPROCATING                 140.   S                                      1000 GALLONS BURNED
   NATURAL GAS

      2-01-002-01  TURBINE            14.0       940.   S    413.         42.0        115.     MILLION CUBIC FEET
      2-01-002-02  RECIPROCATING                 940.   S                                      MILLION CUBIC FEET

   DIESEL

      2-01-003-01  RECIPROCATING      13.0       140.   S    370.         37.0        225.     THOUSANDS OF GALLONS
      2-01-003-02  TURBINE             5.00      140.   S     67.8         5.57        15.4    1000 GALLONS BURNED

   RESIDUAL OIL

      2-01-004-01  TURBINE                       159.   S                                      1000 GALLONS BURNED

   JET FUEL

      2-01-005-01  TURBINE                         6.20                                        1000 GALLONS BURNED

   CRUDE OIL

      2-01-006-01  TURBINE                       146.   S                                      1000 GALLONS BURNED

   PROCESS GAS

      2-01-007-01  TURBINE                       950.   S                                      MILLION CUBIC FEET

   OTHER/NOT CLASIFD

      2-01-999-97  SPECIFY IN REMARK                                                           MILLION CUBIC FEET BURNED
      2-01-999-98  SPECIFY IN REMARK                                                           1000 GALLONS BURNED

INTERNLCOMBUSTION -INDUSTRIAL
*****************  *****************


   DISTILLATE OIL

      2-02-001-01  TURBINE             5.00      140.   S     67.8         5.57        15.4    1000 GALLONS BURNED
      2-02-001-02  RECIPROCATING      33.5       144.   S    469.         37.5        102.     1000 GALLONS BURNED

   NATURAL GAS

      2-02-002-01  TURBINE            14.0       940.   S    413.         42.0        115.     MILLION CUBIC FEET
      2-02-002-02  RECIPROCATING                 940.   S                                      MILLION CUBIC FEET

   GASOLINE

      2-02-003-01  RECIPROCATING       6.50        5.30      102.        161.       3,940.     1000 GALLONS BURNED

   DIESEL FUEL

      2-02-004-01  RECIPROCATING      33.5       144.   S    469.         37.5        102.     1000 GALLONS BURNED
      2-02-004-02  TURBINE             5.00      140.   S     67.8         5.57        15.4    1000 GALLONS BURNED

   RESIDUAL OIL

      2-02-005-01  TURBINE                       159.   S                                      1000 GALLONS BURNED

   JET FUEL

      2-02-006-01  TURBINE                         6.20                                        1000 GALLONS BURNED

   CRUDE OIL

      2-02-007-01  TURBINE                       146.   S                                      1000 GALLONS BURNED

   PROCESS GAS

      2-02-008-01  TURBINE                       950.   S                                      MILLION CUBIC FEET
      2-02-008-02  RECIPROCATING                 950.   S                                      MILLION CUBIC FEET BURNED

   OTHER/NOT CLASIFD

      2-02-999-97  SPECIFY IN REMARK                                                           MILLION CUBIC FEET BURNED
      2-02-999-98  SPECIFY IN REMARK                                                           1000 GALLONS BURNED




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                                    N A T I O N A L   E M I S S I O N   D A T A   S Y S T E M
                                     S O U R C E   C L A S S I F I C A T I O N   C O D E S
                                       P O U N D S   E M I T T E D   P E R   U N I T
INTERNLCOMBUSTION -COMMERCL-INSTUTNL      PART        SOX         NOX          HC
*****************  *****************                                                      CO        U N I T S
  DIESEL

     2-03-001-01  RECIPROCATING
  OTHER/NOT CLASIFD                      33.5        199.  S     469.
                                                                              37.5        102.    THOUSANDS OF GALLONS
     2-03-999-97  SPECIFY IN REMARK
     2-03-999-98  SPECIFY IN REMARK
INTERNLCOMBUSTION -ENGINE TESTING
*****************  *****************                                                              MILLION CUBIC FEET BURNED
                                                                                                   1000 GALLONS BURNED
  AIRCRAFT

     2-04-001-01  TURBOJET
                                         11.8        13.0
  ROCKET MOTOR                                                   14.6         46.0
                                                                                          32.7    THOUSANDS OF GALLON/FUEL
     2-04-002-01  SOLID PROPELLANT
  OTHER/NOT CLASIFD

     2-04-999-97  SPECIFY IN REMARK                                                               TONS OF FUEL
     2-04-999-98  SPECIFY IN REMARK
     2-04-999-99  SPECIFY IN REMARK
INDUSTRIAL PROCES -CHEMICAL MFG                                                                   MILLION CUBIC FEET BURNED
*****************  *****************                                                              1000 GALLONS BURNED
                                                                                                  TONS BURNED
  ADIPIC ACID PROD

     3-01-001-01  GENERAL-CYCLONEX
     3-01-001-99  OTHER/NOT CLASIFD        0.          0.         12.0
  AMMONIA W/METHNTR                                                            0.
                                                                                         0.   TONS PRODUCED
     3-01-002-01  PURGE GAS                                                                   TONS PRODUCED
     3-01-002-02  STORAGE/LOADING          0.
                                           0.          0.
  AMMONIA W/COARSRB                                    0.          0.         90.0
                                                                   0.                    0.   TONS PRODUCED
                                                                               0.        0.   TONS PRODUCED
     3-01-003-01  REGENERATOR EXIT
     3-01-003-02  PURGE GAS                0.          0.
     3-01-003-03  STORAGE/LOADING          0.          0.          0.          0.        200.
     3-01-003-99  OTHER/NOT CLASIFD        0.          0.          0.         90.0            TONS PRODUCED
  AMMONIUM NITRATE                                                 0.                    0.   TONS PRODUCED
                                                                               0.        0.   TONS PRODUCED
     3-01-004-01  GENERAL                                                                     TONS PRODUCED
     3-01-004-99  OTHER/NOT CLASIFD                    0.
  CARBON BLACK
                                                                                              TONS PRODUCED
                                                                                              TONS PRODUCED
     3-01-005-01  CHANNEL PROCESS    2,300.
     3-01-005-02  THERMAL PROCESS                      0.
     3-01-005-03  FURNACE PROC GAS          0.         0.          0.   11,500.     33,800.
     3-01-005-04  FURNACE PROC OIL                                 0.           0.            TONS PRODUCED
     3-01-005-05  FURNACE W/GAS/OIL                                     1,800.            0.  TONS PRODUCED
     3-01-005-99  OTHER/NOT CLASFD     220.                              900.      5,300.     TONS PRODUCED
  CHARCOAL MFG                                                                    4,800.      TONS PRODUCED
                                                                                              TONS PRODUCED
     3-01-006-01  PYROL/DISTIL/GENL    400.                                                   TONS PRODUCT
     3-01-006-99  OTHER/NOT CLASFD
  CHLORINE                                                               100.       320.      TONS PRODUCED
                                                                                              TONS PRODUCT
     3-01-007-01  GENERAL
     3-01-007-99  OTHER/NOT CLASIFD                    0.
  CHLOR-ALKALI
                                                                                              TONS PRODUCED
                                                                                              TONS PRODUCED
     3-01-008-01  LIQUIFTN-DIAPHRGM
     3-01-008-02  LIQUIFTN-MERC CEL                    0.
     3-01-008-03  LOADING TNKC1RVNT                    0.
     3-01-008-04  LOADING STGTNKVNT        0.          0.                                     100 TONS CHLORINE LIQUFFIED
     3-01-008-05  AIR-BLOW MC BRINE        0.          0.          0.                         100 TONS CHLORINE LIQUEFIED
     3-01-008-99  OTHER/NOT CLASIFD        0.          0.          0.          0.        0.   100 TONS CHLORINE LIQUEFI.3
  CLEANING CHEMICLS                                                0.          0.        0.   100 TONS CHLORINE LIQUFFIED
                                                                               0.        0.   100 TONS CHLORINE LIQUFFIED
     3-01-009-01  SOAP/DET SPRYDRYR     90.0                                                  100 TONS CHLORINE LIQUFFIED
     3-01-009-10  SPECIALTY CLEANRS
     3-01-009-99  OTHERS/NOT CLASFD                    0.
                                                                                              TONS PRODUCED
                                                                                              TONS PRODUCT
                                                                                              TONS PRODUCED

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NATIONAL EMISSION DATA SYSTEM
SOURCE CLASSIFICATION CODES

INDUSTRIAL PROCES -CHEMICAL MFG		POUNDS EMITTED PER UNIT PART	SOX	NOX	HC	CO	UNITS
EXPLOSIVES-TNT							
3-01-010-01	NITRATION REACTRS	0.	0.	160.	0.	0.	TONS PRODUCED
3-01-010-02	HNO3 CONCTRTRS	0.	0.	4.00	0.	0.	TONS PRODUCED
3-01-010-03	H2SO4 REGENERATR	0.	15.0	2.00	0.	0.	TONS PRODUCED
3-01-010-04	RED WATER INCIN	32.0	2.00	30.0	0.	0.	TONS PRODUCED
3-01-010-05	OPEN WASTE BURN						TONS BURNED
3-01-010-06	SELLITE EXHAUST	0.	0.70	0.	0.	0.	TONS PRODUCED
3-01-010-99	OTHER/NOT CLASIFD						TONS PRODUCED
HYDROCHLORIC ACID							
3-01-011-01	BYPRODUCTW/OSCRUB		0.				TONS FINAL ACID
3-01-011-02	BYPRODUCT W/SCRUB		0.				TONS FINAL ACID
3-01-011-99	OTHER/NOT CLASIFD						TONS FINAL ACID
HYDROFLUORIC ACID							
3-01-012-01	ROTRYKILNW/SCRUBR	0.					TONS ACID
3-01-012-02	ROTRYKILNW/OSCRUB	0.					TONS ACID
3-01-012-03	GRIND/DRY FLUOSPR	200.					TONS FLUORSPAR
3-01-012-99	OTHER/NOT CLASIFD						TONS ACID
NITRIC ACID							
3-01-013-01	AMMONIAOXIDATNOLD			52.5			TONS PURE ACID PRODUCED
3-01-013-02	AMMONIAOXIDATNNEW			4.50			TONS PURE ACID PRODUCED
3-01-013-03	NITACD CONCTR OLD			5.00			TONS PURE ACID PRODUCED
3-01-013-04	NITACD CONCTR NEW			0.20			TONS PURE ACID PRODUCED
3-01-013-05	UNCONTROLLED						TONS PURE ACID PRODUCED
3-01-013-06	W/CATYL/COMBUSTER						TONS PURE ACID PRODUCED
3-01-013-07	UNCONTROLLED						TONS PURE ACID PRODUCED
3-01-013-08	W/ABSORBERS						TONS PURE ACID PRODUCED
3-01-013-99	OTHER/NOT CLASIFD						TONS PURE ACID PRODUCED
PAINT MFG							
3-01-014-01	GENERAL	2.00			30.0		TONS PRODUCED
3-01-014-02	PIGMENT KILN						TONS PRODUCT
3-01-014-99	OTHER/NOT CLASFD						TONS PRODUCT
VARNISH MFG							
3-01-015-01	BODYING OIL GENL	0.			40.0		TONS PRODUCED
3-01-015-02	OLEORESINOUS GENL	0.			150.		TONS PRODUCED
3-01-015-03	ALKYD GENERAL	0.			160.		TONS PRODUCED
3-01-015-05	ACRYLIC GENERAL	0.			20.0		TONS PRODUCED
3-01-015-99	OTHER/NOT CLASFD						TONS PRODUCED
PHOS-ACID WETPROC							
3-01-016-01	REACTOR-UNCONTLD	0.					TONS PHOSPHATE ROCK
3-01-016-02	GYPSUM POND	0.					TONS PHOSPHATE ROCK
3-01-016-03	CONDENSR-UNCONTLD	0.					TONS PHOSPHATE ROCK
3-01-016-99	OTHER/NOT CLASFD						TONS PRODUCED
PHOS-ACID THERMAL							
3-01-017-01	GENERAL						TONS PHOSPHOROUS BURNED
3-01-017-99	OTHER/NOT CLASFD						TONS PRODUCED
PLASTICS							
3-01-018-01	PVC-GENERAL	35.0					TONS PRODUCED
3-01-018-02	POLYPROD-GENERAL	3.00					TONS PRODUCED
3-01-018-05	BAKELITE-GENERAL						TONS PRODUCT
3-01-018-99	OTHER/NOT CLASFD						TONS PRODUCED
PHTHALIC ANHYDRID							
3-01-019-03	UNCONTROLLED-GENL				32.0		TONS PRODUCED
PRINTING INK							
3-01-020-01	COOKING-GENERAL	0.			120.		TONS PRODUCED
3-01-020-02	COOKING-OILS	0.			40.0		TONS PRODUCED
3-01-020-03	COOKING-OLEORESIN	0.			150.		TONS PRODUCED
3-01-020-04	COOKING-ALKYDS	0.			160.		TONS PRODUCED
3-01-020-05	PIGMENT MIXINGGEN	2.00					TONS PIGMENT
3-01-020-99	OTHER/NOT CLASFD						TONS PRODUCED
SODIUM CARBONATE							
3-01-021-01	SOLVAY-NH3 RECVRY	0.					TONS PRODUCED
3-01-021-02	SOLVAY-HANDLING	6.00					TONS PRODUCED
3-01-021-10	TRONA-CALCINING						TONS PRODUCT
3-01-021-11	TRONA-DRYER						TONS PRODUCED
3-01-021-20	BRINE EVAP-GENERL						TONS PRODUCED
3-01-021-99	OTHER/NOT CLASFD						TONS PRODUCED

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                                     N A T I O N A L   E M I S S I O N   D A T A   S Y S T E M
                                      S O U R C E   C L A S S I F I C A T I O N   C O D E S

                                          P O U N D S   E M I T T E D   P E R   U N I T
                                          PART         SOX          NOX          HC           CO         U N I T S
INDUSTRIAL PROCES -CHEMICAL MFG
****************  ****************

  H2SO4 -CHAMBER

    3-01-022-01  GENERAL                                                         0.                 TONS PURE ACID PRODUCED
  H2SO4-CONTACT

    3-01-023-01  99.7 CONVERSION         2.50         4.00                                          TONS PURE ACID PRODUCED
    3-01-023-04  99.5 CONVERSION         2.50         7.00                                          TONS PURE ACID PRODUCED
    3-01-023-06  99.0 CONVERSION         2.50        14.0                                           TONS PURE ACID PRODUCED
    3-01-023-08  98.0 CONVERSION         2.50        27.0                                           TONS PURE ACID PRODUCED
    3-01-023-10  97.0 CONVERSION         2.50        40.0                                           TONS PURE ACID PRODUCED
    3-01-023-12  96.0 CONVERSION         2.50        55.0                                           TONS PURE ACID PRODUCED
    3-01-023-14  95.0 CONVERSION         2.50        70.0                                           TONS PURE ACID PRODUCED
    3-01-023-16  94.0 CONVERSION         2.50        82.0                                           TONS PURE ACID PRODUCED
    3-01-023-18  93.0 CONVERSION         2.50        96.0                                           TONS PURE ACID PRODUCED
    3-01-023-99  OTHER/NOT CLASFD                                                                   TONS PRODUCED

  SYNTHETIC FIBERS

    3-01-024-01  NYLON GENERAL                                                  7.00                TONS FIBER
    3-01-024-02  DACRON GENERAL                                                 0.                  TONS FIBER
    3-01-024-03  ORLON                                                                              TONS PRODUCT
    3-01-024-04  ELASTIC                                                                            TONS PRODUCT
    3-01-024-05  TEFLON                                                                             TONS PRODUCT
    3-01-024-06  POLYESTER                                                                          TONS PRODUCT
    3-01-024-08  NOMEX                                                                              TONS PRODUCT
    3-01-024-10  ACRYLIC                                                                            TONS PRODUCT
    3-01-024-12  TYVEX                                                                              TONS PRODUCT
    3-01-024-14  OLEFINS                                                                            TONS PRODUCT
    3-01-024-99  OTHERS/NOT CLASFD                                                                  TONS PRODUCED

  SEMISYNTHTICFIBR

    3-01-025-01  RAYON  GENERAL                                                 0.                  TONS FIBER
    3-01-025-05  ACETATE                                                                            TONS PRODUCED
    3-01-025-10  VISCOSE                                                                            TONS PRODUCED
    3-01-025-99  OTHERS/NOT CLASFD                                                                  TONS PRODUCED

  SYNTHETIC RUBBER

    3-01-026-01  BUTADIENE-GENERAL                                                                  TONS PRODUCT
    3-01-026-02  METHYLPROPENE-GNL                                                                  TONS PRODUCT
    3-01-026-03  BUTYNE GENERAL                                                                     TONS PRODUCT
    3-01-026-04  PENTADIENE-GENRL                                                                   TONS PRODUCT
    3-01-026-05  DIMETHHEPTNE GENL                                                                  TONS PRODUCT
    3-01-026-06  PENTANE-GENERAL                                                                    TONS PRODUCT
    3-01-026-07  ETHANENITRILE-GEN                                                                  TONS PRODUCT
    3-01-026-08  ACRYLONITRILE-GEN                                                                  TONS PRODUCT
    3-01-026-09  ACROLEIN-GENERAL                                                                   TONS PRODUCT
    3-01-026-20  AUTO TIRES GENERL                                                                  TONS PRODUCT
    3-01-026-99  OTHER/NOT CLASFD                                                                   TONS PRODUCT

  FERTILIZ AMONNITR

    3-01-027-01  PRILTWR-NEUTRLIZR       0.                        0.                                   TONS PRODUCED
    3-01-027-02  PRILLING TOWER          0.90                      0.                                   TONS PRODUCED
    3-01-027-03  PRILTWR-DRYCOOLRS      12.0                       0.                                   TONS PRODUCED
    3-01-027-04  GRANULAT-NEUTLIZR       0.                        0.                                   TONS PRODUCED
    3-01-027-05  GRANULATOR              0.90                      0.45                                 TONS PRODUCED
    3-01-027-06  GRANULAT-DRYCOOLR       7.00                      3.00                                 TONS PRODUCED

  FERTILIZ-NSUPPHOS

    3-01-028-01  GRIND-DRY               9.00                                                       TONS PRODUCED
    3-01-028-02  MAIN STACK              0.                                                         TONS PRODUCED

  FERTILIZ-TRPSPHOS

    3-01-029-01  RUN OF PILE             0.                                                         TONS PRODUCED
    3-01-029-02  GRANULAR                0.                                                         TONS PRODUCED

  FERTILIZ-DIAMPHOS

    3-01-030-01  DRYER-COOLERS          80.0                                                        TONS PRODUCED
    3-01-030-02  AMONIAT-GRANULATE       2.00                                                       TONS PRODUCED
    3-01-030-99  OTHER/NOT CLASIFD                                                                  TONS PRODUCED

  TEREPTHALIC ACID

    3-01-031-01  HNO3-PARAXYLENGEN                                 13.0                             TONS PRODUCED
    3-01-031-99  OTHER/NOT CLASIFD                                                                  TONS PRODUCED

  SULFUR(ELEMENTAL)

    3-01-032-01  MOD-CLAUS 2STAGE                     280.                                          TONS PRODUCT
    3-01-032-02  MOD-CLAUS 3STAGE                     189.                                          TONS PRODUCT
    3-01-032-03  MOD-CLAUS 4STAGE                     146.                                          TONS PRODUCT
    3-01-032-99  OTHER/NOT CLASIFD                                                                  TONS PRODUCT

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                                        N A T I O N A L  E M I S S I O N  D A T A  S Y S T E M
                                         S O U R C E  C L A S S I F I C A T I O N  C O D E S

                                          P O U N D S  E M I T T E D  P E R  U N I T
INDUSTRIAL PROCES -CHEMICAL MFG           PART        SOX         NOX          HC          CO        U N I T S
*****************  *****************

  PESTICIDES

     3-01-033-01  MALATHION
     3-01-033-99  OTHER/NOT CLASIFD                                                               GALLONS OF PRODUCT
  AMINES/AMIDES                                                                                   TONS PRODUCED

     3-01-034-01  GENERAL/OTHER
                                                                                                  TONS PRODUCT
  PIGMENT-INORGAN

     3-01-035-01  CALCINATION
     3-01-035-99  OTHER/NOT CLASIFD                                                               TONS OF PRODUCT
                                                                                                  TONS OF PRODUCT
  SODIUM SULFATE

     3-01-036-01  GENERAL/OTHER
     3-01-036-02  KILNS                                                                           TONS PRODUCT
                                                                                                  TONS PRODUCT
  SODIUM SULFITE

     3-01-037-01  GENERAL/OTHER
     3-01-037-02  KILNS                                                                           TONS PRODUCT
                                                                                                  TONS PRODUCT
  SODIUM BICARB

     3-01-038-01  GENERAL
                                                                                                  TONS PRODUCT
  LITHIUM HYDROXIDE

     3-01-039-01  GENERAL
                                                                                                  TONS PRODUCT
  FERTILIZER UREA

     3-01-040-01  GENERAL
                                                                                                  TONS PRODUCT
  NITROCELLULOSE

     3-01-041-01  REACTOR POTS            0.        1.30        21.0
     3-01-041-02  H2SO4 CONCENTRTRS       0.        65.0        29.0          0.          0.  TONS PRODUCED
     3-01-041-03  BOILING TUBS            0.          0.         2.00         0.          0.  TONS PRODUCED
     3-01-041-99  OTHER/NOT CLASIFD                                           0.          0.  TONS PRODUCED
                                                                              0.          0.  TONS PRODUCED
  ADHESIVES

     3-01-050-01  GENL/COMPND UNKWN
                                                                                                  TONS PRODUCT
  ACETATE FLAKE

     3-01-090-99  OTHER/NOT CLASFD
                                                                                                  TONS PRODUCT
  ACETONE

     3-01-091-01  OTHER/NOT CLASFD
                                                                                                  TONS PRODUCT
  MALEIC ANHYDRIDE

     3-01-100-01  GENERAL/OTHER
                                                                                                  TONS PRODUCT
  POLVINL PYRILIDON

     3-01-101-01  GENERAL/OTHER
                                                                                                  TONS PRODUCT
  SULFONIC ACID/ATS

     3-01-110-01  GENERAL/OTHER
                                                                                                  TONS PRODUCT
  ASBESTOS CHEMICAL

     3-01-111-01  CAULKING
     3-01-111-02  SEALANTS                          0.          0.          0.          0.  TONS PRODUCT
     3-01-111-03  BRAKE LINE/GRIND                  0.          0.          0.          0.  TONS PRODUCT
     3-01-111-04  FIRE PROOF MFG                    0.          0.          0.          0.  TONS PRODUCT
     3-01-111-99  OTHERS/NOT CLASFD                 0.          0.          0.          0.  TONS PRODUCT
                                                                                            TONS PRODUCT
  FORMALDEHYDE

     3-01-120-01  SILVER CATALYST
     3-01-120-02  MIXED OXIDE CTLST                                                         TONS PRODUCT
                                                                                            TONS PRODUCT
  ETHYLENE DICHLROE

     3-01-125-01  OXYCHLORINATION
     3-01-125-02  DIRECT CHLRNATION                                                         TONS PRODUCT
                                                                                            TONS PRODUCT
  AMMONIUM SULFATE

     3-01-130-01  NH3-H2SO4 PROCES
     3-01-130-02  COKE OVEN BY-PROD                                                         TONS PRODUCT
     3-01-130-03  CAPROLCTM BY-PROD                                                         TONS PRODUCT
                                                                                            TONS PRODUCT
'A' INDICATES THE ASH CONTENT, 'S' INDICATES THE SULFUR CONTENT OF THE FUEL ON A PERCENT BASIS (BY WEIGHT)
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NATIONAL EMISSION DATA SYSTEM
SOURCE CLASSIFICATION CODES

		POUNDS EMITTED PER UNIT					
		PART	SOX	NOX	HC	CO	UNITS
INDUSTRIAL PROCES -CHEMICAL MFG **************** ****************							
WASTE GAS FLARES							
3-01-900-99	OTHER/NOT CLASIFD OTHER/NOT CLASIFD						MILLION CUBIC FEET BURNED
3-01-999-99	SPECIFY IN REMARK						TONS PRODUCT
INDUSTRIAL PROCES -FOOD/AGRICULTURAL **************** ****************							
ALFALFA DEHYDRATN							
3-02-001-01	GENERAL	60.0					TONS MEAL PRODUCED
3-02-001-99	OTHER/NOT CLASFD						TONS PRODUCT
COFFEE ROASTING							
3-02-002-01	DIRECTFIRE ROASTR	7.60		0.10			TONS GREEN BEANS
3-02-002-02	INDIRCTFIREROASTR	4.20		0.10			TONS GREEN BEANS
3-02-002-03	STONER/COOLER	1.40		0.			TONS GREEN BEANS
3-02-002-99	OTHER/NOT CLASFD						TONS PRODUCT
COFFEE-INSTANT							
3-02-003-01	SPRAY DRIER	1.40		0.			TONS GREEN BEANS
COTTON GINNING							
3-02-004-01	UNLOADING FAN	5.00	0.	0.	0.	0.	BALES COTTON
3-02-004-02	CLEANER	1.00	0.	0.	0.	0.	BALES COTTON
3-02-004-03	STICK/BURR MACHNE	3.00	0.	0.	0.	0.	BALES COTTON
3-02-004-99	OTHER/NOT CLASFD						BALES COTTON
FEED/GRAIN TERMEL							
3-02-005-01	SHIPING/RECEIVING	1.00	0.	0.	0.	0.	TONS GRAIN PROCESSED
3-02-005-02	TRANSFER/CONVEYNG	2.00	0.	0.	0.	0.	TONS GRAIN PROCESSED
3-02-005-03	SCREENING/CLEANNG	5.00	0.	0.	0.	0.	TONS GRAIN PROCESSED
3-02-005-04	DRYING	6.00					TONS GRAIN PROCESSED
FEED/GRAIN CNTRYE							
3-02-006-01	SHIPNG/RECEIVNG	5.00	0.	0.	0.	0.	TONS GRAIN PROCESSED
3-02-006-02	TRANSFER/CONVEYNG	3.00	0.	0.	0.	0.	TONS GRAIN PROCESSED
3-02-006-03	SCREENING/CLEANNG	8.00	0.	0.	0.	0.	TONS GRAIN PROCESSED
3-02-006-04	DRYING	7.00					TONS GRAIN PROCESSED
3-02-006-99	OTHER/NOT CLASIFD						TONS GRAIN PROCESSED
GRAIN PROCESSING							
3-02-007-01	CORN MEAL	5.00					TONS GRAIN PROCESSED
3-02-007-02	SOY BEAN	7.00					TONS GRAIN PROCESSED
3-02-007-03	BARLEY/WHEATCLEAN	0.20					TONS GRAIN PROCESSED
3-02-007-04	MILO CLEANER	0.40					TONS GRAIN PROCESSED
3-02-007-05	BARLEYFLOUR MILL	3.00					TONS GRAIN PROCESSED
3-02-007-06	WET CORN MILLING		0.				TONS OF PRODUCT
3-02-007-30	WHEAT FLOUR MILL		0.				TONS PRODUCT
3-02-007-99	OTHER/NOT CLASFD						TONS PROCESSED
FEED MANUF[illegible]TURE							
3-02-008-01	BARLEY FEED-GENL	3.00					TONS GRAIN PROCESSED
3-02-008-99	OTHER/NOT CLASFD						TONS PROCESSED
FERMENTATN-BEER							
3-02-009-01	GRAIN HANDLING	3.00			0.		TONS GRAIN PROCESSED
3-02-009-02	DRYING SPNT GRAIN	5.00					TONS GRAIN PROCESSED
3-02-009-03	BREWING						THOUSANDS OF GALLONS
3-02-009-98	OTHER/NOT CLASFD						GALLONS PRODUCT
3-02-009-99	OTHER/NOT CLASFD						TONS GRAIN PROCESSED
FERMENTATN-WHISKY							
3-02-010-01	GRAIN HANDLING	3.00			0.		TONS GRAIN PROCESSED
3-02-010-02	DRYING SPNT GRAIN	5.00					TONS GRAIN PROCESSED
3-02-010-03	AGING	0.			10.0		BARREL(50 GAL)
3-02-010-99	OTHER/NOT CLASFD						GALLONS PRODUCT
FERMENTATN-WINE							
3-02-011-01	GENERAL	0.			0.		GALLONS PRODUCT
FISH MEAL							
3-02-012-01	COOKERS-FRESHFISH	0.					TONS FISH MEAL PRODUCED
3-02-012-02	COOKERS-STALEFISH	0.					TONS FISH MEAL PRODUCED
3-02-012-03	DRIERS	0.10					TONS FISH SCRAP
3-02-012-99	OTHER/NOT CLASIFD						TONS PROCESSED

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NATIONAL EMISSION DATA SYSTEM
SOURCE CLASSIFICATION CODES

		POUNDS EMITTED PER UNIT					
INDUSTRIAL PROCES -FOOD/AGRICULTURAL		PART	SOX	NOX	HC	CO	UNITS
MEAT SMOKING							
3-02-013-01	GENERAL	0.30			0.07	0.60	TONS MEAT SMOKED
STARCH MFG							
3-02-014-01	GENERAL	8.00					TONS STARCH PRODUCED
SUGAR CANE PROCES							
3-02-015-01	GENERAL						TONS SUGAR PRODUCED
3-02-015-99	OTHER/NOT CLASIFD						TONS PROCESSED
SUGAR BEET PROCES							
3-02-016-01	DRYER ONLY						TONS RAW BEETS
3-02-016-99	OTHER/NOT CLASIFD						TONS RAW BEETS
PEANUT PROCESSING							
3-02-017-20	OIL/NOT CLASFD						TONS PRODUCT
3-02-017-99	OTHER/NOT CLASFD						TONS PROCESSED
CANDY/CONFECTNRY							
3-02-018-99	OTHER/NOT CLASFD						TONS PRODUCT
DAIRY PRODUCTS							
3-02-030-01	MILK SPRAY-DRYER		0.				TONS PRODUCT
3-02-030-99	OTHER/NOT CLASFD						TONS PRODUCT
OTHER/NOT CLASIFD							
3-02-999-98	SPECIFY IN REMARK						TONS PROCESSED (INPUT)
3-02-999-99	SPECIFY IN REMARK						TONS PRODUCED (FINISHED)
INDUSTRIAL PROCES -PRIMARY METALS							
ALUMINUM ORE-BAUX							
3-03-000-01	CRUSHING/HANDLING	6.00					TONS OF ORE
AL ORE-ELECROREDN							
3-03-001-01	PREBAKE CELLS	81.3					TONS ALUMINUM PRODUCED
3-03-001-02	HORIZSTD SODERBRG	98.4					TONS ALUMINUM PRODUCED
3-03-001-03	VERTSTD SODERBERG	78.4					TONS ALUMINUM PRODUCED
3-03-001-04	MATERIALS HANDLNG	10.0					TONS ALUMINUM PRODUCED
3-03-001-05	ANODE BAKE FURNCE	3.00					TONS ALUMINUM PRODUCED
3-03-001-99	OTHER/NOT CLASFD						TONS ALUMINUM PRODUCED
AL ORE-CALC ALHYD							
3-03-002-01	GENERAL	200.					TONS ALUMINUM PRODUCED
COKE MET BYPRODUC							
3-03-003-01	GENERAL	3.50	4.00	0.04	4.20	1.27	TONS COAL CHARGED
3-03-003-02	OVEN CHARGING	1.50	0.02	0.03	2.50	0.60	TONS COAL CHARGED
3-03-003-03	OVEN PUSHING	0.60			0.20	0.07	TONS COAL CHARGED
3-03-003-04	QUENCHING	0.90					TONS COAL CHARGED
3-03-003-05	UNLOADING	0.40					TONS COAL CHARGED
3-03-003-06	UNDERFIRING		4.00				TONS COAL CHARGED
3-03-003-07	COAL CRUSH/HANDL						TONS COAL CHARGED
3-03-003-99	OTHER/NOT CLASFD						TONS COAL CHARGED
COKE MET-BEEHIVE							
3-03-004-01	GENERAL	200.	0.	0.	8.00	1.00	TONS COAL CHARGED
COPPER SMELTER							
3-03-005-01	TOTAL/GENERAL	135.	1,250.				TONS CONCENTRATED ORE
3-03-005-02	ROASTING	45.0	60.0				TONS CONCENTRATED ORE
3-03-005-03	SMELTING	20.0	320.				TONS CONCENTRATED ORE
3-03-005-04	CONVERTING	60.0	870.				TONS CONCENTRATED ORE
3-03-005-05	REFINING	10.0	0.				TONS CONCENTRATED ORE
3-03-005-06	ORE DRYER						TONS OF ORE
3-03-005-08	FINISH OPER-GENL						TONS PRODUCED
3-03-005-99	OTHER/NOT CLASFD						TONS CONCENTRATED ORE
FERALLOY OPEN FNC							
3-03-006-01	50% FESI	200.					TONS PRODUCED
3-03-006-02	75% FESI	315.					TONS PRODUCED
3-03-006-03	90% FESI	565.					TONS PRODUCED
3-03-006-04	SILICON METAL	625.					TONS PRODUCED
3-03-006-05	SILICOMANGANESE	195.					TONS PRODUCED

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441<

NATIONAL EMISSION DATA SYSTEM
SOURCE CLASSIFICATION CODES

		POUNDS EMITTED PER UNIT PART	SOX	NOX	HC	CO	UNITS
INDUSTRIAL PROCES -PRIMARY METALS							
FERROALLOY	CONTINUED						
3-03-006-10	SCREENING			0.			TONS PROCESSED
3-03-006-11	ORE DRYER						TONS PROCESSED
3-03-006-12	LOWCARB CR-REACTR						TONS PROCESSED
3-03-006-99	OTHER/NOT CLASFD						TONS PRODUCED
FERALOY SEMCOVFNC							
3-03-007-01	FEROMANGANESE	45.0					TONS PRODUCED
3-03-007-02	GENERAL						TONS PRODUCED
IRON PRODUCTION							
3-03-008-01	BLAST FNC-ORECHG	121.	0.	0.	0.	1,750.	TONS PRODUCED
3-03-008-02	BLAST FNC-AGLCHG	44.0	0.	0.	0.	0.	TONS PRODUCED
3-03-008-03	SINTERING GENERAL	42.0				44.0	TONS PRODUCED
3-03-008-04	ORE-CRUSH/HANDLE			0.	0.		TONS OF ORE
3-03-008-05	SCARFING	1.00	0.	0.	0.	0.	TONS PROCESSED
3-03-008-06	SAND HANDLING OPN		0.				TONS HANDLED
3-03-008-07	MOLD OVENS						TONS SAND BAKED
3-03-008-08	SLAG CRUSH/HANDL						TONS HANDLED
3-03-008-99	OTHER/NOT CLASFD						TONS PRODUCED
STEEL PRODUCTION							
3-03-009-01	OPNHEARTH OXLANCE	17.4				0.	TONS PRODUCED
3-03-009-02	OPNHEARTH NOXLNCE	8.30				0.	TONS PRODUCED
3-03-009-03	BOF-GENERAL	51.0				139.	TONS PRODUCED
3-03-009-04	ELECT ARC W/LANCE	11.0				18.0	TONS PRODUCED
3-03-009-05	ELECT ARC NOLANCE	9.20				18.0	TONS PRODUCED
3-03-009-10	FINISH/PICKLING						TONS PRODUCED
3-03-009-11	FINISH/SOAK PITS						TONS PRODUCED
3-03-009-12	FINISH/GRIND,ETC						TONS PRODUCED
3-03-009-20	FINISH/OTHER						TONS PRODUCED
3-03-009-99	OTHER/NOT CLASFD						TONS PRODUCED
LEAD SMELTERS							
3-03-010-01	SINTERING	169.	423.	0.	0.	0.	TONS CONCENTRATED ORE
3-03-010-02	BLAST FURNACE	278.	34.9	0.	0.	0.	TONS CONCENTRATED ORE
3-03-010-03	REVERB FURNACE	19.9	0.	0.	0.	0.	TONS CONCENTRATED ORE
3-03-010-04	ORE CRUSHING	2.00	0.	0.	0.	0.	TONS OF ORE CRUSHED
3-03-010-05	MATERIALS HANDLNG	5.00	0.	0.	0.	0.	TONS OF LEAD PRODUCT
3-03-010-99	OTHER/NOT CLASFD						TONS CONCENTRATED ORE
MOLYBDENUM							
3-03-011-01	MINING-GENERAL			0.			HUNDREDS OF TONS MINED
3-03-011-02	MILLING-GENERAL			0.			TONS PRODUCT
3-03-011-99	PROCESS-OTHER						TONS PROCESSED
TITANIUM PROCESS							
3-03-012-01	CHLORINATION STAT		0.	0.	0.		TONS PRODUCT
3-03-012-99	OTHER/NOT CLASIFD						TONS PROCESSED
GOLD							
3-03-013-01	MINING/PROCESSING				0.		TONS ORE
BARIUM							
3-03-014-01	ORE GRIND			0.			TONS PROCESSED
3-03-014-02	REDUCTN KILN						TONS PROCESSED
3-03-014-03	DRIERS/CALCINERS						TONS PROCESSED
3-03-014-99	OTHER/NOT CLASFD						TONS PROCESSED
BERYLLIUM ORE							
3-03-015-01	STORAGE		0.	0.	0.	0.	TONS OF ORE
3-03-015-02	CRUSHING		0.	0.	0.	0.	TONS PROCESSED
3-03-015-03	MELTING				0.		TONS PROCESSED
3-03-015-04	QUENCH/HEAT TREAT		0.	0.	0.	0.	TONS PROCESSED
3-03-015-05	GRINDING		0.	0.	0.	0.	TONS PROCESSED
3-03-015-06	SULFATION/DISSOLV			0.	0.	0.	TONS PROCESSED
3-03-015-07	SINTERING				0.		TONS PROCESSED
3-03-015-08	VENTILATION				0.		TONS PROCESSED
3-03-015-09	LEACH/FILTER		0.	0.	0.	0.	TONS PROCESSED
3-03-015-99	OTHER/NOT CLASFD				0.		TONS PROCESSED
MERCURY MINING							
3-03-025-01	SURFACE BLASTING		0.	0.	0.	0.	TONS OF ORE
3-03-025-02	SURFACE DRILLING		0.	0.	0.	0.	TONS OF ORE
3-03-025-03	SURFACE HANDLING		0.	0.	0.	0.	TONS OF ORE
3-03-025-04	NATURAL VAPOR	0.	0.	0.	0.	0.	TONS OF ORE
3-03-025-05	STRIPPING		0.	0.	0.	0.	TONS REMOVED
3-03-025-06	LOADING		0.	0.	0.	0.	TONS OF ORE
3-03-025-07	CONVEY/HAULING		0.	0.	0.	0.	TONS OF ORE
3-03-025-08	UNLOADING		0.	0.	0.	0.	TONS OF ORE

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442<

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                                        NATIONAL EMISSION DATA SYSTEM
                                        SOURCE CLASSIFICATION CODES

                                         POUNDS EMITTED PER UNIT
                                           PART       SOX        NOX        HC         CO          UNITS
INDUSTRIAL PROCES -PRIMARY METALS
*****************  *****************

   MERCURY MINING     CONTINUED

     3-03-025-09  CONV/HAUL WASTE                     0.         0.         0.         0.  TONS OF ORE
     3-03-025-99  OTHER/NOT CLASFD                                                         TONS OF ORE
   MERCURY ORE PROCS

     3-03-026-01  CRUSHING                            0.         0.         0.         0.  TONS PROCESSED
     3-03-026-02  ROTARY FURNACE                                            0.             TONS PROCESSED
     3-03-026-03  RETORT FURNACE                                            0.             TONS PROCESSED
     3-03-026-04  CALCINE                             0.         0.         0.         0.  TONS PROCESSED
     3-03-026-05  BURNT ORE BIN                       0.         0.         0.         0.  TONS PROCESSED
     3-03-026-06  HOEING PROCESS                      0.         0.         0. 2       0.  TONS PROCESSED
     3-03-026-99  OTHER/NOT CLASFD                                                         TONS PROCESSED

   ZINC SMELTING

     3-03-030-01  GENERAL                                                   0.             TONS PROCESSED
     3-03-030-02  ROASTNG/MULT-HRTH    120.      1,100.                                    TONS PROCESSED
     3-03-030-03  SINTERING             90.0                                               TONS PROCESSED
     3-03-030-04  HORIZ RETORTS          8.00                                              TONS PROCESSED
     3-03-030-05  VERT RETORTS         100.                                                TONS PROCESSED
     3-03-030-06  ELECTROLYTIC PROC      3.00                                              TONS PROCESSED
     3-03-030-99  OTHER/NOT CLASFD                                                         TONS PROCESSED

   OTHER/NOT CLASFD

     3-03-999-99  SPECIFY IN REMARK                                                        TONS PRODUCED

INDUSTRIAL PROCES -SECONDARY METALS
*****************  *****************


   ALUMINUM OPERATN

     3-04-001-01  SWEATINGFURNACE       14.5                                               TONS PRODUCED
     3-04-001-02  SMELT-CRUCIBLE         1.90                                              TONS METAL PRODUCED
     3-04-001-03  SMELT-REVERB FNC       4.30                                              TONS METAL PRODUCED
     3-04-001-04  CHLORINATN STATN      12.5          0.         0.         0.         0.  TONS METAL PRODUCED
     3-04-001-10  FOIL ROLLING                                                         0.  TONS PRODUCT
     3-04-001-11  FOIL CONVERTING                                                      0.  TONS PRODUCED
     3-04-001-20  CAN MANUFACTURE                                                      0.  TONS PRODUCED
     3-04-001-50  ROLL-DRAW-EXTRUDE                                                    0.  TONS PRODUCED
     3-04-001-99  OTHER/NOT CLASFD                                                         TONS PRODUCED

   BRASS/BRONZ MELT

     3-04-002-01  BLAST FNC             18.0                                               TONS CHARGE
     3-04-002-02  CRUCIBLE FNC          12.0                                               TONS CHARGE
     3-04-002-03  CUPOLA FNC            73.0                                               TONS CHARGE
     3-04-002-04  ELECT INDUCTION        2.00                                              TONS CHARGE
     3-04-002-05  REVERB FNC            70.0                                               TONS CHARGE
     3-04-002-06  ROTARY FNC            60.0                                               TONS CHARGE
     3-04-002-99  OTHER/NOT CLASIFD                                                        TONS PRODUCED

   GRAY IRON

     3-04-003-01  CUPOLA                17.0                                         145.  TONS METAL CHARGE
     3-04-003-02  REVERB FNC             2.00                                          0.  TONS METAL CHARGE
     3-04-003-03  ELECT INDUCTION        1.50                                          0.  TONS METAL CHARGE
     3-04-003-05  ANNEALING OPERATN                                                        TONS METAL CHARGE
     3-04-003-30  MISC CAST-FABCTN                                                         TONS PROCESSED
     3-04-003-40  GRINDING-CLEANING                   0.         0.         0.         0.  TONS PROCESSED
     3-04-003-50  SAND HANDL-GENL                                                          TONS HANDLED
     3-04-003-99  OTHER/NOT CLASIFD                                                        TONS METAL CHARGE

   LEAD SMELT SEC

     3-04-004-01  POT FURNACE            0.80         0.         0.         0.         0.  TONS METAL CHARGED
     3-04-004-02  REVERB FNC           147.          80.0        0.         0.         0.  TONS METAL CHARGED
     3-04-004-03  BLAST/CUPOLA FNC     193.          53.0        0.         0.         0.  TONS METAL CHARGED
     3-04-004-04  ROTARY REVERB FNC     70.0          0.         0.         0.         0.  TONS METAL CHARGED
     3-04-004-08  LEAD OXIDE MFG                                                           TONS PROCESSED
     3-04-004-99  OTHER/NOT CLASIFD                                                        TONS PROCESSED

   LEAD BATTERY

     3-04-005-01  TOTAL-GENERAL          0.90         0.         0.         0.         0.  TONS OF BATTERIES PRODUCED
     3-04-005-02  CASTING FURNACE        0.04         0.         0.         0.         0.  TONS OF BATTERIES PRODUCED
     3-04-005-03  PASTE MIXER            0.21         0.         0.         0.         0.  TONS OF BATTERIES PRODUCED
     3-04-005-04  THREE PROCES OPER      0.64         0.         0.         0.         0.  TONS OF BATTERIES PRODUCED
     3-04-005-99  OTHER/NOT CLASIFD                                                        TONS PROCESSED

   MAGNESIUM SEC

     3-04-006-01  POT FURNACE            4.00                                              TONS PROCESSED
     3-04-006-99  OTHER/NOT CLASIFD                                                        TONS PROCESSED


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```

443<

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                                          POUNDS EMITTED PER UNIT
                                         PART       SOX        NOX        HC         CO        UNITS
INDUSTRIAL PROCES -SECONDARY METALS
*****************  *****************

  STEEL FOUNDRY

    3-04-007-01  ELECTRIC ARC FNC      13.0                  0.20                             TONS PROCESSED
    3-04-007-02  OPEN HEARTH FNC       11.0                  0.01                             TONS PROCESSED
    3-04-007-03  OPEN HEARTH LANCD     10.0                  0.                               TONS PROCESSED
    3-04-007-04  HEAT-TREAT FNC                                                               TONS PROCESSED
    3-04-007-05  INDUCTION FURNACE      0.10      0.         0.         0.         0.         TONS PROCESSED
    3-04-007-06  SAND GRIND/HANDL                                                             TONS HANDLED
    3-04-007-10  FINISH/SOAK PITS                                                             TONS PROCESSED
    3-04-007-15  FINISH/NOT CLASFD                                                            TONS PROCESSED
    3-04-007-99  OTHER/NOT CLASIFD                                                            TONS PROCESSED

  ZINC SEC

    3-04-008-01  RETORT FNC            47.0                                                   TONS PRODUCED
    3-04-008-02  HORIZ MUFFLE FNC      45.0                                                   TONS PRODUCED
    3-04-008-03  POT FURNACE            0.10                                                  TONS PRODUCED
    3-04-008-04  KETTLE-SWEAT FNC      11.0                                                   TONS PRODUCED
    3-04-008-05  GALVANIZING KETTL      5.00                                                  TONS PRODUCED
    3-04-008-06  CALCINING KILN        89.0                                                   TONS PRODUCED
    3-04-008-07  CONCENTRATE DRYER                                                            TONS PROCESSED
    3-04-008-08  REVERB-SWEAT FNC      13.0                                                   TONS PRODUCED
    3-04-008-99  OTHER/NOT CLASIFD                                                            TONS PROCESSED

  MALLEABLE IRON

    3-04-009-01  ANNEALING OPERATN                                                            TONS METAL CHARGE
    3-04-009-99  OTHER/NOT CLASIFD                                                            TONS METAL CHARGE

  NICKEL

    3-04-010-01  FLUX FURNACE                                                                 TONS PROCESSED
    3-04-010-99  OTHER/NOT CLASIFD                                                            TONS PROCESSED

  ZIRCONIUM

    3-04-011-01  OXIDE KILN                                                                   TONS PROCESSED
    3-04-011-99  OTHER/NOT CLASIFD                                                            TONS PROCESSED

  FURNACE ELECTRODE

    3-04-020-01  CALCINATION                                                                  TONS PROCESSED
    3-04-020-02  MIXING                           0.         0.         0.         0.         TONS PROCESSED
    3-04-020-03  PITCH TREATING                   0.         0.                               TONS PROCESSED
    3-04-020-04  BAKE FURNACES                                                                TONS PROCESSED
    3-04-020-99  OTHER/NOT CLASIFD                                                            TONS PROCESSED

  MISC CAST&FABRCTN

    3-04-050-01  SPECIFY IN REMARK                                                            TONS PRODUCED

  OTHER/NOT CLASIFD

    3-04-999-99  SPECIFY IN REMARK                                                            TONS PROCESSED

INDUSTRIAL PROCES -MINERAL PRODUCTS
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  ASPHALT ROOFING

    3-05-001-01  BLOWING OPERATION      2.50                            1.50       0.90       TONS SATURATED FELT PRODUCED
    3-05-001-02  DIPPING ONLY           1.00                            0.         0.         TONS SATURATED FELT PRODUCED
    3-05-001-03  SPRAYING ONLY          3.00                            0.         0.         TONS SATURATED FELT PRODUCED
    3-05-001-04  DIPPING/SPRAYING       2.00                            0.         0.         TONS SATURATED FELT PRODUCED
    3-05-001-99  OTHER/NOT CLASIFD                                                            TONS SATURATED FELT PRODUCED

  ASPHALTIC CONCRET

    3-05-002-01  ROTARY DRYER          35.0                                                   TONS PRODUCED
    3-05-002-02  OTHER SOURCES         10.0       0.         0.         0.         0.         TONS PRODUCED
    3-05-002-99  OTHER/NOT CLASIFD                                                            TONS PRODUCED

  BRICK MANUFACTURE

    3-05-003-01  DRYING-RAW MTL        70.0                  0.                               TONS PRODUCED
    3-05-003-02  GRINDING-RAW MTL      76.0                  0.                               TONS PRODUCED
    3-05-003-03  STORAGE-RAW MTL       34.0                  0.                               TONS PRODUCED
    3-05-003-04  CURING GAS FIRED       0.07      0.02       0.29       0.03       0.07       TONS PRODUCED
    3-05-003-05  CURING OIL FIRED       0.07      5.00 S     1.40       0.10       0.         TONS PRODUCED
    3-05-003-06  CURING COAL FIRED      1.30 A    9.60 S     1.10       0.70       2.60       TONS PRODUCED
    3-05-003-99  OTHER/NOT CLASIFD                                                            TONS PRODUCED

  CALCIUM CARBIDE

    3-05-004-01  ELECTRIC FNC          38.0       3.00                                        TONS PRODUCED
    3-05-004-02  COKE DRYER             2.00      3.00                                        TONS PRODUCED
    3-05-004-03  FNC ROOM VENTS        26.0       0.                                          TONS PRODUCED
    3-05-004-99  OTHER/NOT CLASIFD                                                            TONS PROCESSED

'A' INDICATES THE ASH CONTENT, 'S' INDICATES THE SULFUR CONTENT OF THE FUEL ON A PERCENT BASIS (BY WEIGHT)
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NATIONAL EMISSION DATA SYSTEM
SOURCE CLASSIFICATION CODES

INDUSTRIAL PROCES -MINERAL PRODUCTS		POUNDS EMITTED PER UNIT					
		PART	SOX	NOX	HC	CO	UNITS
CASTABLE REFRACTY							
3-05-005-01	RAWMATL DRYER	30.0					TONS FEED MATERIAL
3-05-005-02	RAWMATL CRUSH/PRC	120.					TONS FEED MATERIAL
3-05-005-03	ELECTRIC ARC MELT	50.0					TONS FEED MATERIAL
3-05-005-04	CURING OVEN	0.20					TONS FEED MATERIAL
3-05-005-05	MOLD/SHAKEOUT	25.0					TONS FEED MATERIAL
3-05-005-99	OTHER/NOT CLASIFD						TONS FEED MATERIAL
CEMENT MFG DRY							
3-05-006-01	KILNS	46.0	3.00	0.50			BARRELS CEMENT PRODUCED
3-05-006-02	DRYERS/GRINDERETC	18.0					BARRELS CEMENT PRODUCED
3-05-006-03	KILNS-OIL FIRED	245.	14.4	2.60	0.	0.	TONS CEMENT PRODUCED
3-05-006-04	KILNS-GAS FIRED	245.	10.2	2.60	0.	0.	TONS CEMENT PRODUCED
3-05-006-05	KILNS-COAL FIRED	245.	23.8	2.60	0.	0.	TONS CEMENT PRODUCED
3-05-006-99	OTHER/NOT CLASIFD						TONS CEMENT PRODUCED
CEMENT MFG WET							
3-05-007-01	KILNS	43.0	3.00	0.50	0.	0.	BARRELS CEMENT PRODUCED
3-05-007-02	DRYERS/GRINDERETC	6.00					BARRELS CEMENT PRODUCED
3-05-007-03	KILNS-OIL FIRED	228.	14.4	2.60	0.	0.	TONS CEMENT PRODUCED
3-05-007-04	KILNS GAS FIRED	228.	10.2	2.60	0.	0.	TONS CEMENT PRODUCED
3-05-007-05	KILNS-COAL FIRED	228.	23.8	2.60	0.	0.	TONS CEMENT PRODUCED
3-05-007-99	OTHER/NOT CLASIFD						TONS CEMENT PRODUCED
CERAMIC/CLAY MFG							
3-05-008-01	DRYING	70.0					TONS INPUT TO PROCESS
3-05-008-02	GRINDING	76.0					TONS INPUT TO PROCESS
3-05-008-03	STORAGE	34.0					TONS INPUT TO PROCESS
3-05-008-99	OTHER/NOT CLASIFD						TONS PRODUCED
CLAY/FLYASHSINTER							
3-05-009-01	FLYASH	110.					TONS FINISHED PRODUCT
3-05-009-02	CLAY/COKE	55.0					TONS FINISHED PRODUCT
3-05-009-03	NATURAL CLAY	24.0					TONS FINISHED PRODUCT
3-05-009-99	OTHER/NOT CLASIFD						TONS PRODUCED
COAL CLEANING							
3-05-010-01	THERM/FLUID BED	20.0					TONS COAL DRIED
3-05-010-02	THERM/FLASH	16.0					TONS COAL DRIED
3-05-010-03	THERM/MULTILOUVRD	25.0					TONS COAL DRIED
3-05-010-99	OTHER/NOT CLASIFD						TONS COAL CLEANED
CONCRETE BATCHING							
3-05-011-01	GENERAL	0.20					CUBIC YARDS CONCRETE PRODUCED
3-05-011-20	ASBEST/CEMNT PDTS	0.20	0.	0.	0.	0.	TONS PRODUCT
3-05-011-21	ROAD SURFACE		0.	0.	0.	0.	TONS PRODUCT
3-05-011-99	OTHER/NOT CLASFD						TONS PRODUCT
FIBERGLASS MFG							
3-05-012-01	REVERBFNC-REGENEX	3.00					TONS MATERIAL PROCESSED
3-05-012-02	REVERBFNC-RECUPEX	1.00					TONS MATERIAL PROCESSED
3-05-012-03	ELECTRIC IND FNC	0.					TONS MATERIAL PROCESSED
3-05-012-04	FORMING LINE	50.0					TONS MATERIAL PROCESSED
3-05-012-05	CURING OVEN	7.00					TONS MATERIAL PROCESSED
3-05-012-99	OTHER/NOT CLASIFD						TONS PROCESSED
FRIT MFG							
3-05-013-01	ROTARY FNC GENL	16.0					TONS CHARGE
3-05-013-99	OTHER/NOT CLASIFD						TONS CHARGED
GLASS MFG							
3-05-014-01	SODALIME GENL FNC	2.00					TONS GLASS PRODUCED
3-05-014-10	RAW MAT REC/STORG						TONS PROCESSED
3-05-014-11	BATCHING/MIXING		0.	0.	0.	0.	TONS PROCESSED
3-05-014-12	MOLTEN HOLD TANKS		0.				TONS PROCESSED
3-05-014-99	OTHER/NOT CLASIFD						TONS PRODUCED
GYPSUM MFG							
3-05-015-01	RW MTL DRYER	40.0					TONS THROUGHPUT
3-05-015-02	PRIMARY GRINDER	1.00					TONS THROUGHPUT
3-05-015-03	CALCINER	90.0					TONS THROUGHPUT
3-05-015-04	CONVEYING	0.70					TONS THROUGHPUT
3-05-015-99	OTHER/NOT CLASIFD						TONS THROUGHPUT
LIME MFG							
3-05-016-01	PRIMARY CRUSHING	31.0	0.	0.	0.	0.	TONS PROCESSED
3-05-016-02	SECNDRY CRUSHING	2.00	0.	0.	0.	0.	TONS PROCESSED
3-05-016-03	CALCINNG-VERTKILN	8.00					TONS PROCESSED

'A' INDICATES THE ASH CONTENT, 'S' INDICATES THE SULFUR CONTENT OF THE FUEL ON A PERCENT BASIS (BY WEIGHT)

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                                          N A T I O N A L   E M I S S I O N   D A T A   S Y S T E M
                                           S O U R C E   C L A S S I F I C A T I O N   C O D E S

                                              P O U N D S   E M I T T E D   P E R   U N I T
                                               PART         SOX          NOX          HC           CO        U N I T S
INDUSTRIAL PROCES -MINERAL PRODUCTS
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   LIME MFG           CONTINUED

      3-05-016-04  CALCINING-ROTYKILN    200.                                                          TONS PROCESSED
      3-05-016-05  CALCIMATIC KILN                                                                     TONS PROCESSED
      3-05-016-06  FLUIDIZD BED KILN                                                                   TONS PROCESSED
      3-05-016-09  HYDRATOR                                                                            TONS HYDRATED LIME PRODUCED
      3-05-016-99  OTHER/NOT CLASIFD                                                                   TONS PROCESSED

   MINERAL WOOL

      3-05-017-01  CUPOLA                22.0         0.02                                             TONS CHARGE
      3-05-017-02  REVERB FNC             5.00                                                         TONS CHARGE
      3-05-017-03  BLOW CHAMBER          17.0                                                          TONS CHARGE
      3-05-017-04  CURING OVEN            4.00                                                         TONS CHARGE
      3-05-017-05  COOLER                 2.00                                                         TONS CHARGE
      3-05-017-99  OTHER/NOT CLASIFD                                                                   TONS PROCESSED

   PERLITE MFG

      3-05-018-01  VERTICAL FNC GEN      21.0                                                          TONS CHARGE
      3-05-018-99  OTHER/NOT CLASIFD                                                                   TONS PROCESSED

   PHOSPHATE ROCK

      3-05-019-01  DRYING                15.0                                                          TONS PHOSPHATE ROCK
      3-05-019-02  GRINDING              20.0                                                          TONS PHOSPHATE ROCK
      3-05-019-03  TRANSFER/STORAGE       2.00                                                         TONS PHOSPHATE ROCK
      3-05-019-04  OPEN STORAGE          40.0                                                          TONS PHOSPHATE ROCK
      3-05-019-99  OTHER/NOT CLASIFD                                                                   TONS PROCESSED

   STONE QUARY/PROC

      3-05-020-01  PRIMARY CRUSHING       0.50         0.           0.           0.           0.  TONS RAW MATERIAL
      3-05-020-02  SEC CRUSH/SCREEN       1.50         0.           0.           0.           0.  TONS RAW MATERIAL
      3-05-020-03  TERT CRUSH/SCREEN      6.00         0.           0.           0.           0.  TONS RAW MATERIAL
      3-05-020-04  RECRUSH/SCREENING      5.00         0.           0.           0.           0.  TONS RAW MATERIAL
      3-05-020-05  FINES MILL             6.00         0.           0.           0.           0.  TONS RAW MATERIAL
      3-05-020-06  SCREEN/CONVY/HNDL      2.00         0.           0.           0.           0.  TONS PRODUCT
      3-05-020-07  OPEN STORAGE          10.0          0.           0.           0.           0.  TONS PRODUCT STORED
      3-05-020-08  CUT STONE-GENERAL                   0.           0.           0.           0.  TONS PROCESSED
      3-05-020-09  BLASTING-GENERAL                    0.           0.           0.           0.  TONS PROCESSED
      3-05-020-99  OTHER/NOT CLASIFD                                                                   TONS PROCESSED

   SALT MINING

      3-05-021-01  GENERAL                             0.                                              TONS MINED

   POTASH PRODUCTION

      3-05-022-01  MINE-GRIND/DRY                      0.                                              TONS ORE
      3-05-022-99  OTHER/NOT CLASIFD                                                                   TONS PROCESSED

   CALCIUM BORATE

      3-05-023-01  MINING/PROCESSING                                             0.                    TONS PRODUCT
      3-05-023-99  OTHER/NOT CLASIFD                                                                   TONS PROCESSED

   MG CARBONATE

      3-05-024-01  MINE/PROCESS                                                  0.                    TONS PRODUCT
      3-05-024-99  OTHER/NOT CLASIFD                                                                   TONS PROCESSED

   SAND/GRAVEL

      3-05-025-01  CRUSHING/SCREEN        0.10         0.           0.           0.           0.  TONS PRODUCT
      3-05-025-99  OTHER/NOT CLASIFD                                                                   TONS PROCESSED

   DIATOMACOUSERTH

      3-05-026-01  HANDLING                            0.           0.           0.           0.  TONS PRODUCT
      3-05-026-99  OTHER/NOT CLASIFD                                                                   TONS PROCESSED

   CERAMIC ELECT PTS

      3-05-030-99  OTHER/NOT CLASIFD                                                                   TONS PROCESSED

   ASBESTOS MINING

      3-05-031-01  SURFACE BLASTING                    0.           0.           0.           0.  TONS OF ORE
      3-05-031-02  SURFACE DRILLING                    0.           0.           0.           0.  TONS OF ORE
      3-05-031-03  COBBING                             0.           0.           0.           0.  TONS OF ORE
      3-05-031-04  LOADING                             0.           0.           0.           0.  TONS OF ORE
      3-05-031-05  CONVEY/HAUL ASBES                   0.           0.           0.           0.  TONS OF ORE
      3-05-031-06  CONVEY/HAUL WASTE                   0.           0.           0.           0.  TONS OF ORE
      3-05-031-07  UNLOADING                           0.           0.           0.           0.  TONS OF ORE
      3-05-031-08  STRIPPING                           0.           0.           0.           0.  TONS REMOVED
      3-05-031-09  VENTILATION                         0.           0.           0.           0.  TONS OF ORE
      3-05-031-10  STOCKPILING                         0.           0.           0.           0.  TONS OF ORE
      3-05-031-11  TAILINGS                            0.           0.           0.           0.  TINS OF MATERIAL
      3-05-031-99  OTHER/NOT CLASFD                                                                    TONS PROCESSED
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                                   NATIONAL EMISSION DATA SYSTEM
                                   SOURCE CLASSIFICATION CODES

                                      POUNDS EMITTED PER UNIT
INDUSTRIAL PROCES -MINERAL PRODUCTS      PART       SOX        NOX        HC         CO        U N I T S
*****************  *****************

   ASBESTOS MILLING

      3-05-032-01  CRUSHING
      3-05-032-02  DRYING                           0.         0.         0.         0.  TONS PROCESSED
      3-05-032-03  RECRUSHING                       0.         0.         0.         0.  TONS PROCESSED
      3-05-032-04  SCREENING                        0.         0.         0.         0.  TONS PROCESSED
      3-05-032-05  FIBERIZING                       0.         0.         0.         0.  TONS PROCESSED
      3-05-032-06  BAGGING                          0.         0.         0.         0.  TONS PROCESSED
      3-05-032-99  OTHER/NOT CLASFD                 0.         0.         0.         0.  TONS PROCESSED
                                                                                           TONS PROCESSED
   MINING-SPEC MATL

      3-05-040-01  OPEN PIT-BLASTING
      3-05-040-02  OPEN PIT-DRILLING                0.         0.         0.         0.  TONS OF MATERIAL
      3-05-040-03  OPEN PIT-CORBING                 0.         0.         0.         0.  TONS OF MATERIAL
      3-05-040-10  UNDERGRD-VENTILAT                0.         0.         0.         0.  TONS OF MATERIAL
      3-05-040-20  LOADING                          0.         0.         0.         0.  TONS OF MATERIAL
      3-05-040-21  CONVEY/HAUL MATL                 0.         0.         0.         0.  TONS OF MATERIAL
      3-05-040-22  CONVEY/HAUL WASTE                0.         0.         0.         0.  TONS OF MATERIAL
      3-05-040-23  UNLOADING                        0.         0.         0.         0.  TONS OF MATERIAL
      3-05-040-24  STRIPPING                        0.         0.         0.         0.  TONS OF MATERIAL
      3-05-040-25  STOCKPILE                        0.         0.         0.         0.  TONS OF MATERIAL
      3-05-040-30  PRIMARY CRUSHER                  0.         0.         0.         0.  TONS OF MATERIAL
      3-05-040-31  SECONDARY CRUSHER                0.         0.         0.         0.  TONS OF MATERIAL
      3-05-040-32  ORE CONCENTRATOR                 0.         0.         0.         0.  TONS OF MATERIAL
      3-05-040-33  ORE DRYER                        0.         0.         0.         0.  TONS OF MATERIAL
      3-05-040-34  SCREENING                        0.         0.         0.         0.  TONS OF MATERIAL
      3-05-040-36  TAILING PILES                    0.         0.         0.         0.  TONS OF MATERIAL
      3-05-040-99  OTHER/NOT CLASIFD                0.         0.         0.         0.  TONS OF MATERIAL
                                                                                           TONS OF MATERIAL
   OTHER/NOT CLASIFD

      3-05-999-99  SPECIFY IN REMARK

INDUSTRIAL PROCES -PETROLEUM INDRY                                                         TONS PRODUCT
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   PROCESS HEATER

      3-06-001-01  OIL                 840.      6,720.  S  2,900.      140.
      3-06-001-02  GAS                   0.02        0.43 S     0.23      0.03       0.  1000 BARRELS OIL BURNED
      3-06-001-03  OIL                  20.0       160.   S    69.0       3.34       0.  1000 CUBIC FEET GAS BURNED
      3-06-001-04  GAS                  20.0       830.   S   230.       30.0        0.  1000 GALLONS OIL BURNED
   FLUID CRACKERS                                                                    0.  MILLION CUBIC FEET BURNED

      3-06-002-01  GENERAL (FCC)       242.        493.        71.0      220.    13,700.  1000 BARRELS FRESH FEED

   MOV-BED CAT-CRACK

      3-06-003-01  GENERAL (TCC)        17.0        60.0        5.00      87.0    3,800.  1000 BARRELS FRESH FEED

   BLOW-DOWN SYSTM

      3-06-004-01  W/CONTROLS            0.          0.         0.         5.00
      3-06-004-02  W/O CONTROLS          0.          0.         0.       300.        0.  1000 BARRELS REFINERY CAPACITY
   PROCESS DRAINS                                                                    0.  1000 BARRELS REFINERY CAPACITY

      3-06-005-01  GEN W/CONTROL         0.          0.         0.         8.00
      3-06-005-02  GEN W/O CONTROL       0.          0.         0.       210.        0.  1000 BARRELS WASTE WATER
   VACUUM JETS                                                                       0.  1000 BARRELS WASTE WATER

      3-06-006-01  W/CONTROL             0.          0.         0.         0.
      3-06-006-02  W/O CONTROL           0.          0.         0.       130.        0.  1000 BARRELS VACUUM DISTILLATIO
   COOLING TOWERS                                                                    0.  1000 BARRELS VACUUM DISTILLATIO

      3-06-007-01                        0.          0.         0.         6.00      0.  MILLION GALLONS COOLING WATER

   MISCELLANEOUS

      3-06-008-01  PIPE/VALVE-FLANGE     0.          0.         0.        28.0
      3-06-008-02  VESL RELIEF VALVE     0.          0.         0.        11.0       0.  1000 BARRELS REFINERY CAPACITY
      3-06-008-03  PUMP SEALS            0.          0.         0.        17.0       0.  1000 BARRELS REFINERY CAPACITY
      3-06-008-04  COMPRESR SEALS        0.          0.         0.         5.00      0.  1000 BARRELS REFINERY CAPACITY
      3-06-008-05  OTHER-GENL            0.          0.         0.        10.0       0.  1000 BARRELS REFINERY CAPACITY
   FLARES                                                                            0.  1000 BARRELS REFINERY CAPACITY

      3-06-009-01  NATURAL GAS
      3-06-009-99  OTHER/NOT CLASIFD                            0.                        MILLIONS OF CUBIC FEET
                                                                                          MILLIONS OF CUBIC FEET
   SLUDGE CONVERTER

      3-06-010-01  GENERAL
                                                                                          TONS PROCESSED
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                                        NATIONAL EMISSION DATA SYSTEM
                                        SOURCE CLASSIFICATION CODES

                                         POUNDS EMITTED PER UNIT
                                         PART      SOX       NOX       HC        CO        UNITS
INDUSTRIAL PROCES -PETROLEUM INDRY
*****************  ****************

   ASPHALT OXIDIZER

      3-06-011-01  GENERAL                                                                 TONS PROCESSED
      3-06-011-99  OTHER/NOT CLASIFD                                                       TONS PROCESSED
   FLUID COKING

      3-06-012-01  GENERAL               523.                                              1000 BARRELS FRESH FEED
      3-06-012-02  COOLING OPER                                                            1000 BARRELS FRESH FEED
      3-06-012-03  TRANSPORTATION                                                          1000 BARRELS FRESH FEED
      3-06-012-04  STORAGE                                                                 1000 BARRELS FRESH FEED

   CATALYTIC REFORM

      3-06-013-01  GENERAL                                                                 1000 BARRELS FRESH FEED

   OTHER/NOT CLASIFD

      3-06-999-98  SPECIFY IN REMARK                                                       TONS PROCESSED
      3-06-999-99  SPECIFY IN REMARK                                                       BARRELS-PROCESSED

INDUSTRIAL PROCES -WOOD PRODUCTS
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   SULFATE PULPNG

      3-07-001-01  BLOWTNK ACCUMULTR       0.        0.                          0.  AIR-DRY TONS UNBLEACHED PUL
      3-07-001-02  WASHRS/SCREENS          0.        0.                          0.  AIR-DRY TONS UNBLEACHED PUL
      3-07-001-03  MULT-EFFECT EVAP        0.        0.                          0.  AIR-DRY TONS UNBLEACHED PUL
      3-07-001-04  RECVY BOLR/DCEVAP     151.        5.00                       60.0 AIR-DRY TONS UNBLEACHED PUL
      3-07-001-05  SMELT DISSOLV TNK       2.00      0.                          0.  AIR-DRY TONS UNBLEACHED PUL
      3-07-001-06  LIME KILNS             45.0       0.                         10.0 AIR-DRY TONS UNBLEACHED PUL
      3-07-001-07  TURPENTINE CONDSR       0.        0.                          0.  AIR-DRY TONS UNBLEACHED PUL
      3-07-001-08  FLUIDBED CALCINER      72.0       0.                          0.  AIR-DRY TONS UNBLEACHED PUL
      3-07-001-09  LIQUOR OXIDN TOWR                                                 AIR-DRY TONS UNBLEACHED PUL
      3-07-001-99  OTHER/NOT CLASIFD                                                 AIR-DRY TONS UNBLEACHED PUL

   SULFITE PULPING

      3-07-002-01  LIQUOR RECOVERY                                                   AIR-DRY TONS UNBLEACHED PULP
      3-07-002-02  SULFITE TOWER                                                     AIR-DRY TONS UNBLEACHED PULP
      3-07-002-03  DIGESTER                                             0.           AIR-DRY TONS UNBLEACHED PULP
      3-07-002-04  SMELT TANK                                           0.           AIR-DRY TONS UNBLEACHED PULP
      3-07-002-05  EVAPORATORS                                          0.           AIR-DRY TONS UNBLEACHED PULP
      3-07-002-06  PULP DIGESTER                                        0.           TONS AIR DRY PULP
      3-07-002-99  OTHER/NOT CLASIFD                                                 TONS AIR DRY PULP

   PULPBOARD MFG

      3-07-004-01  PAPERBOARD-GEN          0.                                        TONS FINISHED PRODUCT
      3-07-004-02  FIBERBOARD-GEN          0.60                                      TONS FINISHED PRODUCT
      3-07-004-99  OTHER/NOT CLASIFD                                                 TONS FINISHED PRODUCT

   PRESSURE TREATING

      3-07-005-01  CREOSOTE                                                          TONS OF WOOD TREATED
      3-07-005-99  OTHER/NOT CLASIFD                                                 TONS OF WOOD TREATED

   TALLOIL/ROSIN

      3-07-006-01  GENERAL                                                           TONS OF PRODUCT

   PLYWOOD/PARTBOARD

      3-07-007-01  VENEER DRYER            0.        0.                 1.20     0.  TONS PROCESSED
      3-07-007-02  SANDING                           0.        0.       0.       0.  TONS PROCESSED
      3-07-007-99  OTHER/NOT CLASIFD                                                 TONS PROCESSED

   SAWMILL OPERATNS

      3-07-008-99  OTHER/NOT CLASIFD                                                 TONS PROCESSED

   EXCELSIOR MFG

      3-07-009-99  OTHER/NOT CLASIFD                                                 TONS PROCESSED

   CORK PROCESSING

      3-07-010-99  OTHER/NOT CLASIFD                                                 TONS PROCESSED

   FURNITURE MFG

      3-07-020-99  OTHER/NOT CLASIFD                                                 TONS PROCESSED

   OTHER/NOT CLASIFD

      3-07-999-99  SPECIFY IN REMARK                                                 TONS PROCESSED


'A' INDICATES THE ASH CONTENT, 'S' INDICATES THE SULFUR CONTENT OF THE FUEL ON A PERCENT BASIS (BY WEIGHT)
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                                          NATIONAL EMISSION DATA SYSTEM
                                           SOURCE CLASSIFICATION CODES

                                             POUNDS EMITTED PER UNIT
                                         PART      SOX       NOX       HC       CO       UNITS
INDUSTRIAL PROCES -METAL FABRICATION
*****************  ****************

  IRON/STEEL

     3-09-001-01  MISC HARDWARE                    0.        0.                  0.  TONS OF PRODUCT
     3-09-001-02  FARM MACHINERY                   0.        0.                      TONS OF PRODUCT
     3-09-001-99  OTHER/NOT CLASIFD                                                  TONS PROCESSED

  PLATING OPERATONS

     3-09-010-99  OTHER/NOT CLASIFD                                                  TONS PLATED

  CAN MAKING OPRNS

     3-09-020-99  OTHER/NOT CLASIFD                                                  TONS PRODUCT

  MACHINING OPER

     3-09-030-01  DRILLING-SP MATL                 0.        0.        0.        0.  TONS PROCESSED
     3-09-030-02  MILLING-SP MATL                  0.        0.        0.        0.  TONS PROCESSED
     3-09-030-03  REAMING-SP MATL                  0.        0.        0.        0.  TONS PROCESSED
     3-09-030-04  GRINDING-SP MATL                 0.        0.        0.        0.  TONS PROCESSED
     3-09-030-05  SAWING-SP MATL                   0.        0.        0.        0   TONS PROCESSED
     3-09-030-06  HONING-SP MATL                   0.        0.        0.        0.  TONS PROCESSED
     3-09-030-99  OTHER-SP MATL                                                      TONS PROCESSED

  OTHER/NOT CLASIFD

     3-09-999-99  SPECIFY IN REMARK                                                  TONS PROCESSED

INDUSTRIAL PROCES -LEATHER PRODUCTS
*****************  ****************


  OTHER/NOT CLASIFD

     3-20-999-99  SPECIFY IN REMARK                                                  TONS PROCESSED

INDUSTRIAL PROCES -TEXTILE MFG
*****************  ****************


  GENERAL FABRICS

     3-30-001-01  YARN PREP/BLEACH                                                   TONS PROCESSED
     3-30-001-02  PRINTING                                                           TONS PROCESSED
     3-30-001-99  OTHER/NOT SPECIFD                                                  TONS PROCESSED

  RUBBERIZED FABRIC

     3-30-002-01  IMPREGNATION                                                       TONS PROCESSED
     3-30-002-02  WET COATING                                                        TONS PROCESSED
     3-30-002-03  HOT MELT COATING                                                   TONS PROCESSED
     3-30-002-99  OTHER/NOT SPECIFD                                                  TONS PROCESSED

  CARPET OPERATNS

     3-30-003-99  OTHER/NOT SPECIFD                                                  TONS PROCESSED

INDUSTRIAL PROCES -INPROCESS FUEL
*****************  ****************


  ANTHRACITE COAL

     3-90-001-99  OTHER/NOT CLASIFD      0.        0.        0.        0.        0.  TONS BURNED

  BITUMINOUS COAL

     3-90-002-01  CEMENT KILN/DRYER      0.        0.        0.        0.        0.  TONS BURNED
     3-90-002-03  LIME KILN              0.        0.        0.        0.        0.  TONS BURNED
     3-90-002-04  KAOLIN KILN            0.        0.        0.        0.        0.  TONS BURNED
     3-90-002-06  BRICK KILN/DRY         0.        0.        0.        0.        0.  TONS BURNED
     3-90-002-07  GYPSUM KILN/ETC        0.        0.        0.        0.        0.  TONS BURNED
     3-90-002-08  COAL DRYERS            0.        0.        0.        0.        0.  TONS BURNED
     3-90-002-09  ROCK/GRAVEL DRYER      0.        0.        0.        0.        0.  TONS BURNED
     3-90-002-99  OTHER/NOT CLASIFD      0.        0.        0.        0.        0.  TONS BURNED

  RESIDUAL OIL

     3-90-004-01  ASPHALT DRYER          0.        0.        0.        0.        0.  1000 GALLONS BURNED
     3-90-004-02  CEMENT KILN/DRYER      0.        0.        0.        0.        0.  1000 GALLONS BURNED
     3-90-004-03  LIME KILN              0.        0.        0.        0.        0.  1000 GALLONS BURNED
     3-90-004-04  KAOLIN KILN            0.        0.        0.        0.        0.  1000 GALLONS BURNED
     3-90-004-05  METAL MELTING          0.        0.        0.        0.        0.  1000 GALLONS BURNED
     3-90-004-06  BRICK KILN/DRY         0.        0.        0.        0.        0.  1000 GALLONS BURNED
     3-90-004-07  GYPSUM KILN/ETC        0.        0.        0.        0.        0.  1000 GALLONS BURNED
     3-90-004-08  GLASS FURNACE          0.        0.        0.        0.        0.  1000 GALLONS BURNED
     3-90-004-09  ROCK/GRAVEL DRYER      0.        0.        0.        0.        0.  1000 GALLONS BURNED
     3-90-004-10  FRIT SMELTER           0.        0.        0.        0.        0.  1000 GALLONS BURNED
     3-90-004-11  PERLITE FURNACE        0.        0.        0.        0.        0.  1000 GALLONS BURNED
     3-90-004-30  FEED/GRAIN DRYING      0.        0.        0.        0.        0.  1000 GALLONS BURNED
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NATIONAL EMISSION DATA SYSTEM
SOURCE CLASSIFICATION CODES

INDUSTRIAL PROCES -INPROCESS FUEL ***************** *****************		POUNDS EMITTED PER UNIT PART	SOX	NOX	HC	CO	UNITS
RESIDUAL OIL	CONTINUED						
3-90-004-31	FOOD-DRY/COOK/ETC	0.	0.	0.	0.	0.	1000 GALLONS BURNED
3-90-004-32	FERTILIZER DRYING	0.	0.	0.	0.	0.	1000 GALLONS BURNED
3-90-004-50	PULPBOARD-DRYERS	0.	0.	0.	0.	0.	1000 GALLONS BURNED
3-90-004-51	PLYWOOD-DRYERS	0.	0.	0.	0.	0.	1000 GALLONS BURNED
3-90-004-52	PULP-RECOV BOILER	0.	0.	0.	0.	0.	1000 GALLONS BURNED
3-90-004-99	OTHER/NOT CLASIFD	0.	0.	0.	0.	0.	1000 GALLONS BURNED
DISTILLATE OIL							
3-90-005-01	ASPHALT DRYER	0.	0.	0.	0.	0.	1000 GALLONS BURNED
3-90-005-02	CEMENT KILN/DRYER	0.	0.	0.	0.	0.	1000 GALLONS BURNED
3-90-005-03	LIME KILN	0.	0.	0.	0.	0.	1000 GALLONS BURNED
3-90-005-04	KAOLIN KILN	0.	0.	0.	0.	0.	1000 GALLONS BURNED
3-90-005-05	METAL MELTING	0.	0.	0.	0.	0.	1000 GALLONS BURNED
3-90-005-06	BRICK KILN/DRY	0.	0.	0.	0.	0.	1000 GALLONS BURNED
3-90-005-07	GYPSUM KILN/ETC	0.	0.	0.	0.	0.	1000 GALLONS BURNED
3-90-005-08	GLASS FURNACE	0.	0.	0.	0.	0.	1000 GALLONS BURNED
3-90-005-09	ROCK/GRAVEL DRYER	0.	0.	0.	0.	0.	1000 GALLONS BURNED
3-90-005-10	FRIT SMELTER	0.	0.	0.	0.	0.	1000 GALLONS BURNED
3-90-005-11	PERLITE FURNACE	0.	0.	0.	0.	0.	1000 GALLONS BURNED
3-90-005-30	FEED/GRAIN DRYING	0.	0.	0.	0.	0.	1000 GALLONS BURNED
3-90-005-31	FOOD-DRY/COOK/ETC	0.	0.	0.	0.	0.	1000 GALLONS BURNED
3-90-005-32	FERTILIZER DRYING	0.	0.	0.	0.	0.	1000 GALLONS BURNED
3-90-005-50	PULPBOARD-DRYERS	0.	0.	0.	0.	0.	1000 GALLONS BURNED
3-90-005-51	PLYWOOD-DRYERS	0.	0.	0.	0.	0.	1000 GALLONS BURNED
3-90-005-52	PULP-RECOV BOILER	0.	0.	0.	0.	0.	1000 GALLONS BURNED
3-90-005-99	OTHER/NOT CLASIFD	0.	0.	0.	0.	0.	1000 GALLONS BURNED
NATURAL GAS							
3-90-006-01	ASPHALT DRYER	0.	0.	0.	0.	0.	MILLION CUBIC FEET BURNED
3-90-006-02	CEMENT KILN/DRYER	0.	0.	0.	0.	0.	MILLION CUBIC FEET BURNED
3-90-006-03	LIME KILN	0.	0.	0.	0.	0.	MILLION CUBIC FEET BURNED
3-90-006-04	KAOLIN KILN	0.	0.	0.	0.	0.	MILLION CUBIC FEET BURNED
3-90-006-05	METAL MELTING	0.	0.	0.	0.	0.	MILLION CUBIC FEET BURNED
3-90-006-06	BRICK KILN/DRYS	0.	0.	0.	0.	0.	MILLION CUBIC FEET BURNED
3-90-006-07	GYPSUM KILN ETC	0.	0.	0.	0.	0.	MILLION CUBIC FEET BURNED
3-90-006-08	GLASS FURNACE	0.	0.	0.	0.	0.	MILLION CUBIC FEET BURNED
3-90-006-09	ROCK/GRAVEL DRYER	0.	0.	0.	0.	0.	MILLION CUBIC FEET BURNED
3-90-006-10	FRIT SMELTER	0.	0.	0.	0.	0.	MILLION CUBIC FEET BURNED
3-90-006-11	PERLITE FURNACE	0.	0.	0.	0.	0.	MILLION CUBIC FEET BURNED
3-90-006-30	FEED/GRAIN DRYING	0.	0.	0.	0.	0.	MILLION CUBIC FEET BURNED
3-90-006-31	FOOD-DRY/COOK/ETC	0.	0.	0.	0.	0.	MILLION CUBIC FEET BURNED
3-90-006-32	FERTILIZER DRYING	0.	0.	0.	0.	0.	MILLION CUBIC FEET BURNED
3-90-006-50	PULPBOARD-DRYERS	0.	0.	0.	0.	0.	MILLION CUBIC FEET BURNED
3-90-006-51	PLYWOOD-DRYERS	0.	0.	0.	0.	0.	MILLION CUBIC FEET BURNED
3-90-006-52	PULP-RECOV BOILER	0.	0.	0.	0.	0.	MILLION CUBIC FEET BURNED
3-90-006-99	OTHER/NOT CLASIFD	0.	0.	0.	0.	0.	MILLION CUBIC FEET BURNED
PROCESS GAS							
3-90-007-01	CO/BLAST FURNACE	0.	0.	0.	0.	0.	MILLION CUBIC FEET BURNED
3-90-007-02	COKE OVEN GAS	0.	0.	0.	0.	0.	MILLION CUBIC FEET BURNED
3-90-007-99	OTHER/NOT CLASIFD	0.	0.	0.	0.	0.	MILLION CUBIC FEET BURNED
COKE							
3-90-008-01	MINERAL WOOL FURN	0.	0.	0.	0.	0.	TONS BURNED
3-90-008-99	OTHER/NOT CLASIFD	0.	0.	0.	0.	0.	TONS
WOOD							
3-90-009-99	OTHER/NOT CLASIFD	0.	0.	0.	0.	0.	TONS BURNED
LIQ PET GAS (LPG)							
3-90-010-99	OTHER/NOT CLASIFD	0.	0.	0.	0.	0.	1000 GALLONS BURNED
OTHER/NOT CLASIFD							
3-90-999-97	SPECIFY IN REMARK	0.	0.	0.	0.	0.	MILLION CUBIC FEET BURNED
3-90-999-98	SPECIFY IN REMARK	0.	0.	0.	0.	0.	1000 GALLONS BURNED
3-90-999-99	SPECIFY IN REMARK	0.	0.	0.	0.	0.	TONS BURNED
INDUSTRIAL PROCES -OTHER/NOT CLASIFD ***************** *****************							
SPECIFY IN REMARK							
3-99-999-99							TONS PROCESSED

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NATIONAL EMISSION DATA SYSTEM
SOURCE CLASSIFICATION CODES

POINT SC EVAP	-CLEANING SOLVENT	PART	SOX	NOX	HC	CO	UNITS
		POUNDS EMITTED PER UNIT					
DRYCLEANING							
4-01-001-01	PERCHLORETHYLENE	0.	0.	0.	210.	0.	TONS CLOTHES CLEANED
4-01-001-02	STODDARD	0.	0.	0.	305.	0.	TONS CLOTHES CLEANED
4-01-001-99	SPECIFY SOLVENT						TONS CLOTHES CLEANED
DEGREASING							
4-01-002-01	STODDARD	0.	0.	0.		0.	TONS SOLVENT USED
4-01-002-02	TRICHLOROETHANE						TONS SOLVENT USED
4-01-002-03	PERCHLOROETHYLENE						TONS SOLVENT USED
4-01-002-04	METHYLENE CHLORDE						TONS SOLVENT USED
4-01-002-05	TRICHLOROETHYLENE						TONS SOLVENT USED
4-01-002-06	TOLUENE						TONS SOLVENT USED
4-01-002-99	OTHER/NOT CLASIFD						TONS SOLVENT USED
OTHER/NOT CLASIFD							
4-01-999-99	SPECIFY IN REMARK						TONS SOLVENT USED

POINT SC EVAP	-SURFACE COATING	PART	SOX	NOX	HC	CO	UNITS
PAINT							
4-02-001-01	GENERAL	0.	0.	0.	1,120.	0.	TONS COATING
4-02-001-02	ACETONE				2,000.		TONS SOLVENT IN COATING
4-02-001-03	ETHYL ACETATE				2,000.		TONS SOLVENT IN COATING
4-02-001-04	MEK				2,000.		TONS SOLVENT IN COATING
4-02-001-05	TOLUENE				2,000.		TONS SOLVENT IN COATING
4-02-001-99	SOLVENT GENERAL				2,000.		TONS SOLVENT IN COATING
VARNISH/SHELLAC							
4-02-003-01	GENERAL				1,000.		TONS COATING
4-02-003-02	ACETONE				2,000.		TONS SOLVENT IN COATING
4-02-003-03	ETHYL ACETATE				2,000.		TONS SOLVENT IN COATING
4-02-003-04	TOLUENE				2,000.		TONS SOLVENT IN COATING
4-02-003-05	XYLENE				2,000.		TONS SOLVENT IN COATING
4-02-003-99	SOLVENT GENERAL				2,000.		TONS SOLVENT IN COATING
LAQUER							
4-02-004-01	GENERAL				1,540.		TONS COATING
4-02-004-02	ACETONE				2,000.		TONS SOLVENT IN COATING
4-02-004-03	ETHYL ACETATE				2,000.		TONS SOLVENT IN COATING
4-02-004-04	ISOPROPYL ALCOHOL				2,000.		TONS SOLVENT IN COATING
4-02-004-05	MEK				2,000.		TONS SOLVENT IN COATING
4-02-004-06	TOLUENE				2,000.		TONS SOLVENT IN COATING
4-02-004-07	XYLENE				2,000.		TONS SOLVENT IN COATING
4-02-004-99	SOLVENT GENERAL				2,000.		TONS SOLVENT IN COATING
ENAMEL							
4-02-005-01	GENERAL	0.	0.	0.	840.	0.	TONS COATING
4-02-005-02	CELLOSOLVE ACETAT				2,000.		TONS SOLVENT IN COATING
4-02-005-03	MEK				2,000.		TONS SOLVENT IN COATING
4-02-005-04	TOLUENE				2,000.		TONS SOLVENT IN COATING
4-02-005-05	XYLENE				2,000.		TONS SOLVENT IN COATING
4-02-005-99	SOLVENT GENERAL				2,000.		TONS SOLVENT IN COATING
PRIMER							
4-02-006-01	GENERAL				1,320.		TONS COATING
4-02-006-02	NAPHTHA				2,000.		TONS SOLVENT IN COATING
4-02-006-03	XYLENE				2,000.		TONS SOLVENT IN COATING
4-02-006-04	MINERAL SPIRITS				2,000.		TONS SOLVENT IN COATING
4-02-006-05	TOLUENE				2,000.		TONS SOLVENT IN COATING
4-02-006-99	SOLVENT GENERAL				2,000.		TONS SOLVENT IN COATING
ADHESIVE							
4-02-007-01	GENERAL						TONS COATING
4-02-007-02	MEK				2,000.		TONS SOLVENT IN COATING
4-02-007-03	TOLUENE				2,000.		TONS SOLVENT IN COATING
4-02-007-04	BENZENE				2,000.		TONS SOLVENT IN COATING
4-02-007-05	NAPHTHA				2,000.		TONS SOLVENT IN COATING
4-02-007-99	SOLVENT GENERAL				2,000.		TONS SOLVENT IN COATING
COATING OVEN							
4-02-008-01	GENERAL						TONS COATING
4-02-008-02	DRIED < 175F						TONS COATING
4-02-008-03	BAKED > 175F						TONS COATING
4-02-008-99	OTHER/SPECIFY						TONS COATING

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                                        N A T I O N A L   E M I S S I O N   D A T A   S Y S T E M
                                         S O U R C E   C L A S S I F I C A T I O N   C O D E S

                                          P O U N D S   E M I T T E D   P E R   U N I T
                                            PART          SOX          NOX            HC           CO          U N I T S
POINT SC EVAP      -SURFACE COATING
*****************  *****************

   SOLVENT

      4-02-009-01  GENERAL                                                          2,000.                    TONS SOLVENT
      4-02-009-02  ACETONE                                                          2,000.                    TONS SOLVENT
      4-02-009-03  BUTYL ACETATE                                                    2,000.                    TONS SOLVENT
      4-02-009-04  BUTYL ALCOHOL                                                    2,000.                    TONS SOLVENT
      4-02-009-05  CARBITOL                                                         2,000.                    TONS SOLVENT
      4-02-009-06  CELLOSOLVE                                                       2,000.                    TONS SOLVENT
      4-02-009-07  CELLOSOLVE ACETAT                                                2,000.                    TONS SOLVENT
      4-02-009-08  DIMETHYLFORMAMIDE                                                2,000.                    TONS SOLVENT
      4-02-009-09  ETHYL ACETATE                                                    2,000.                    TONS SOLVENT
      4-02-009-10  ETHYL ALCOHOL                                                    2,000.                    TONS SOLVENT
      4-02-009-11  GASOLINE                                                         2,000.                    TONS SOLVENT
      4-02-009-12  ISOPROPYL ALCOHOL                                                2,000.                    TONS SOLVENT
      4-02-009-13  ISOPROPYL ACETATE                                                2,000.                    TONS SOLVENT
      4-02-009-14  KEROSENE                                                         2,000.                    TONS SOLVENT
      4-02-009-15  LACTOL SPIRITS                                                   2,000.                    TONS SOLVENT
      4-02-009-16  METHYL ACETATE                                                   2,000.                    TONS SOLVENT
      4-02-009-17  METHYL ALCOHOL                                                   2,000.                    TONS SOLVENT
      4-02-009-18  MEK                                                              2,000.                    TONS SOLVENT
      4-02-009-19  MIBK                                                             2,000.                    TONS SOLVENT
      4-02-009-20  MINERAL SPIRITS                                                  2,000.                    TONS SOLVENT
      4-02-009-21  NAPHTHA                                                          2,000.                    TONS SOLVENT
      4-02-009-22  TOLUENE                                                          2,000.                    TONS SOLVENT
      4-02-009-23  VARSOL                                                           2,000.                    TONS SOLVENT
      4-02-009-24  XYLENE                                                           2,000.                    TONS SOLVENT

   OTHER/NOT CLASIFD

      4-02-999-99  SPECIFY IN REMARK                                                                          TONS COATING

POINT SC EVAP      -PETROL PROD STG
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   FIXED ROOF

      4-03-001-01  BREATH-GASOLINE         0.           0.           0.           80.3           0.  1000 GALLONS STORAGE CAPACITY
      4-03-001-02  BREATH-CRUDE            0.           0.           0.           59.8           0.  1000 GALLONS STORAGE CAPACITY
      4-03-001-03  WORKING-GASOLINE        0.           0.           0.            9.00          0.  1000 GALLONS THROUGHPUT
      4-03-001-04  WORKING-CRUDE           0.           0.           0.            7.30          0.  1000 GALLONS THROUGHPUT
      4-03-001-05  BREATH-JET FUEL         0.           0.           0.           25.2           0.  1000 GALLONS STORAGE CAPACITY
      4-03-001-06  BREATH-KEROSENE         0.           0.           0.           13.1           0.  1000 GALLONS STORAGE CAPACITY
      4-03-001-07  BREATH-DIST FUEL        0.           0.           0.           13.1           0.  1000 GALLONS STORAGE CAPACITY
      4-03-001-08  BREATH-BENZENE          0.           0.           0.           18.3           0.  1000 GALLONS STORAGE CAPACITY
      4-03-001-09  BREATH-CYCLOHEX         0.           0.           0.           20.8           0.  1000 GALLONS STORAGE CAPACITY
      4-03-001-10  BREATH-CYCLOPENT        0.           0.           0.           58.4           0.  1000 GALLONS STORAGE CAPACITY
      4-03-001-11  BREATH-HEPTANE          0.           0.           0.           11.3           0.  1000 GALLONS STORAGE CAPACITY
      4-03-001-12  BREATH-HEXANE           0.           0.           0.           32.1           0.  1000 GALLONS STORAGE CAPACITY
      4-03-001-13  BREATH-ISOOCTANE        0.           0.           0.           13.9           0.  1000 GALLONS STORAGE CAPACITY
      4-03-001-14  BREATH-ISOPENTANE       0.           0.           0.          142.            0.  1000 GALLONS STORAGE CAPACITY
      4-03-001-15  BREATH-PENTANE          0.           0.           0.           94.9           0.  1000 GALLONS STORAGE CAPACITY
      4-03-001-16  BREATH-TOLUENE          0.           0.           0.            5.84          0.  1000 GALLONS STORAGE CAPACITY
      4-03-001-50  WORKING-JET FUEL        0.           0.           0.            2.40          0.  1000 GALLONS THROUGHPUT
      4-03-001-51  WORKING-KEROSENE        0.           0.           0.            1.00          0.  1000 GALLONS THROUGHPUT
      4-03-001-52  WORKING-DIST FUEL       0.           0.           0.            1.00          0.  1000 GALLONS THROUGHPUT
      4-03-001-53  WORKING-BENZENE         0.           0.           0.            2.00          0.  1000 GALLONS THROUGHPUT
      4-03-001-54  WORKING-CYCLOHEX        0.           0.           0.            2.30          0.  1000 GALLONS THROUGHPUT
      4-03-001-55  WORKING-CYCLOPENT       0.           0.           0.            6.40          0.  1000 GALLONS THROUGHPUT
      4-03-001-56  WORKING-HEPTANE         0.           0.           0.            1.20          0.  1000 GALLONS THROUGHPUT
      4-03-001-57  WORKING-HEXANE          0.           0.           0.            3.60          0.  1000 GALLONS THROUGHPUT
      4-03-001-58  WORKING-ISOOCTANE       0.           0.           0.            1.50          0.  1000 GALLONS THROUGHPUT
      4-03-001-59  WORKING-ISOPENT         0.           0.           0.           15.7           0.  1000 GALLONS THROUGHPUT
      4-03-001-60  WORKING-PENTANE         0.           0.           0.           10.6           0.  1000 GALLONS THROUGHPUT
      4-03-001-61  WORKING-TOLUENE         0.           0.           0.            0.64          0.  1000 GALLONS THROUGHPUT
      4-03-001-98  BREATHE-SPECIFY                                                                   1000 GALLONS STORAGE CAPACITY
      4-03-001-99  WORKING-SPECIFY                                                                   1000 GALLONS THRUPUT

   FLOATING ROOF

      4-03-002-01  STAND STG-GASOLN        0.           0.           0.           12.1           0.  1000 GALLONS STORAGE CAPACITY
      4-03-002-02  WORKING-PRODUCT                                                 0.                1000 GALLONS THROUGHPUT
      4-03-002-03  STAND STG-CRUDE         0.           0.           0.           10.6           0.  1000 GALLONS STORAGE CAPACITY
      4-03-002-04  WORKING-CRUDE                                                   0.                1000 GALLONS THROUGHPUT
      4-03-002-05  STAND STG-JETFUEL       0.           0.           0.            4.38          0.  1000 GALLONS STORAGE CAPACITY
      4-03-002-06  STAND STG-KEROSNE       0.           0.           0.            1.90          0.  1000 GALLONS STORAGE CAPACITY
      4-03-002-07  STAND STG-DIST FL       0.           0.           0.            1.90          0.  1000 GALLONS STORAGE CAPACITY
      4-03-002-08  STAND STG-BENZENE       0.           0.           0.            2.70          0.  1000 GALLONS STORAGE CAPACITY
      4-03-002-09  STAND STG-CYCLHEX       0.           0.           0.            3.03          0.  1000 GALLONS STORAGE CAPACITY
      4-03-002-10  STAND STG-CYCLPEN       0.           0.           0.            8.76          0.  1000 GALLONS STORAGE CAPACITY
      4-03-002-11  STAND STG-HEPTANE       0.           0.           0.            1.64          0.  1000 GALLONS STORAGE CAPACITY
      4-03-002-12  STAND STG-HEXANE        0.           0.           0.            4.75          0.  1000 GALLONS STORAGE CAPACITY
      4-03-002-13  STAND STG-ISOOCTN       0.           0.           0.            2.01          0.  1000 GALLONS STORAGE CAPACITY
      4-03-002-14  STAND STG-ISOPENT       0.           0.           0.           20.8           0.  1000 GALLONS STORAGE CAPACITY
      4-03-002-15  STAND STG-PENTANE       0.           0.           0.           13.9           0.  1000 GALLONS STORAGE CAPACITY
      4-03-002-16  STAND STG-TOLUENE       0.           0.           0.            0.88          0.  1000 GALLONS STORAGE CAPACITY
      4-03-002-99  STAND STG-SPECIFY                                                                 1000 GALLONS STORAGE CAPACITY

'A' INDICATES THE ASH CONTENT, 'S' INDICATES THE SULFUR CONTENT OF THE FUEL ON A PERCENT BASIS (BY WEIGHT)
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                                   NATIONAL EMISSION DATA SYSTEM
                                   SOURCE CLASSIFICATION CODES

                                    POUNDS EMITTED PER UNIT
                                     PART      SOX       NOX       HC          CO       UNITS
POINT SC EVAP      -PETROL PROD STG
*****************  ****************

  VAP-VAPOR SPACE

     4-03-003-02  WORKING-GASOLINE     0.        0.        0.      10.2          0.   1000 GALLONS THROUGHPUT
     4-03-003-03  WORKING-JET FUEL     0.        0.        0.       2.30         0.   1000 GALLONS THROUGHPUT
     4-03-003-04  WORKING-KEROSENE     0.        0.        0.       1.00         0.   1000 GALLONS THROUGHPUT
     4-03-003-05  WORKING-DIST FUEL    0.        0.        0.       1.00         0.   1000 GALLONS THROUGHPUT
     4-03-003-06  WORKING-BENZENE      0.        0.        0.       2.30         0.   1000 GALLONS THROUGHPUT
     4-03-003-07  WORKING-CYCLOHEX     0.        0.        0.       2.60         0.   1000 GALLONS THROUGHPUT
     4-03-003-08  WORKING-CYCLOPENT    0.        0.        0.       7.20         0.   1000 GALLONS THROUGHPUT
     4-03-003-09  WORKING-HEPTANE      0.        0.        0.       1.40         0.   1000 GALLONS THROUGHPUT
     4-03-003-10  WORKING-HEXANE       0.        0.        0.       4.00         0.   1000 GALLONS THROUGHPUT
     4-03-003-11  WORKING-ISOOCTANE    0.        0.        0.       1.70         0.   1000 GALLONS THROUGHPUT
     4-03-003-12  WORKING-ISOPENT      0.        0.        0.      17.8          0.   1000 GALLONS THROUGHPUT
     4-03-003-13  WORKING-PENTANE      0.        0.        0.      12.0          0.   1000 GALLONS THROUGHPUT
     4-03-003-14  WORKING-TOLUENE      0.        0.        0.       0.73         0.   1000 GALLONS THROUGHPUT
     4-03-003-99  WORKING-SPECIFY                                                   1000 GALLONS THRUPUT

  OTHER/NOT CLASIFD

     4-03-999-99  SPECIFY IN REMARK                                                 1000 GAL STORED

POINT SC EVAP      -MISC ORGANIC STOR
*****************  ****************

  OTHER/NOT CLASIFD

     4-04-001-99  SPECIFY IN REMARK                                                 TONS STORED

POINT SC EVAP      -PRINTING PRESS
*****************  ****************

  DRYERS

     4-05-001-01  GENERAL                                  0.                       TONS SOLVENT

  LETTERPRESS

     4-05-002-01  GENERAL                                            700.           TONS INK
     4-05-002-02  KEROSENE                                         2,000.           TONS SOLVENT IN INK
     4-05-002-03  MINERAL SPIRITS                                  2,000.           TONS SOLVENT IN INK
     4-05-002-99  SOLVENT GENERAL                                  2,000.           TONS SOLVENT IN INK

  FLEXOGRAPHIC

     4-05-003-01  GENERAL                                          1,300.           TONS INK
     4-05-003-02  CARBITOL                                         2,000.           TONS SOLVENT IN INK
     4-05-003-03  CELLOSOLVE                                       2,000.           TONS SOLVENT IN INK
     4-05-003-04  ETHYL ALCOHOL                                    2,000.           TONS SOLVENT IN INK
     4-05-003-05  ISOPROPYL ALCOHOL                                2,000.           TONS SOLVENT IN INK
     4-05-003-06  N-PROPYL ALCOHOL                                 2,000.           TONS SOLVENT IN INK
     4-05-003-07  NAPHTHA                                          2,000.           TONS SOLVENT IN INK
     4-05-003-99  SOLVENT GENERAL                                  2,000.           TONS SOLVENT IN INK

  LITHOGRAPHIC

     4-05-004-01  GENERAL                                            700.           TONS INK
     4-05-004-02  MINERAL SPIRITS                                  2,000.           TONS SOLVENT IN INK
     4-05-004-03  ISOPROPYL ALCOHOL                                2,000.           TONS SOLVENT IN INK
     4-05-004-99  SOLVENT GENERAL                                  2,000.           TONS SOLVENT IN INK

  GRAVURE

     4-05-005-01  GENERAL                                          1,300.           TONS INK
     4-05-005-02  DIMETHYLFORMAMIDE                                2,000.           TONS SOLVENT IN INK
     4-05-005-03  ETHYL ACETATE                                    2,000.           TONS SOLVENT IN INK
     4-05-005-04  ETHYL ALCOHOL                                    2,000.           TONS SOLVENT IN INK
     4-05-005-05  ISOPROPYL ALCOHOL                                2,000.           TONS SOLVENT IN INK
     4-05-005-06  MEK                                              2,000.           TONS SOLVENT IN INK
     4-05-005-07  MIBK                                             2,000.           TONS SOLVENT IN INK
     4-05-005-08  MINERAL SPIRITS                                  2,000.           TONS SOLVENT IN INK
     4-05-005-09  N-PROPYL ALCOHOL                                 2,000.           TONS SOLVENT IN INK
     4-05-005-10  TOLUENE                                          2,000.           TONS SOLVENT IN INK
     4-05-005-99  SOLVENT GENERAL                                  2,000.           TONS SOLVENT IN INK




'A' INDICATES THE ASH CONTENT, 'S' INDICATES THE SULFUR CONTENT OF THE FUEL ON A PERCENT BASIS (BY WEIGHT)
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                                        N A T I O N A L   E M I S S I O N   D A T A   S Y S T E M
                                         S O U R C E   C L A S S I F I C A T I O N   C O D E S

                                           P O U N D S   E M I T T E D   P E R   U N I T
                                            PART        SOX        NOX        HC          CO        U N I T S
POINT SC EVAP      -PETROL MRKT-TRANS
.................  .................

  TANK CARS/TRUCKS

     4-06-001-01  LOAD(SPLASH)-GASO        0.          0.         0.        12.4          0.  1000 GALLONS TRANSFERRED
     4-06-001-02  LOAD(SPLASH)-CRUD        0.          0.         0.        10.6          0.  1000 GALLONS TRANSFERRED
     4-06-001-03  LOAD(SPLASH)-JET         0.          0.         0.         1.84         0.  1000 GALLONS TRANSFERRED
     4-06-001-04  LOAD(SPLASH)-KERO        0.          0.         0.         0.88         0.  1000 GALLONS TRANSFERRED
     4-06-001-05  LOAD(SPLASH)-DIST        0.          0.         0.         0.93         0.  1000 GALLONS TRANSFERRED
     4-06-001-26  LOAD(SUBM)-GASOLN        0.          0.         0.         4.10         0.  1000 GALLONS TRANSFERRED
     4-06-001-27  LOAD(SUBM)-CRUDE         0.          0.         0.         3.40         0.  1000 GALLONS TRANSFERRED
     4-06-001-28  LOAD(SUBM)-JET FL        0.          0.         0.         0.91         0.  1000 GALLONS TRANSFERRED
     4-06-001-29  LOAD(SUBM)-KEROSN        0.          0.         0.         0.45         0.  1000 GALLONS TRANSFERRED
     4-06-001-30  LOAD(SUBM)-DIST          0.          0.         0.         0.49         0.  1000 GALLONS TRANSFERRED
     4-06-001-51  UNLOAD-GASOLINE          0.          0.         0.         2.10         0.  1000 GALLONS TRANSFERRED
     4-06-001-52  UNLOAD-CRUDE OIL         0.          0.         0.         1.98         0.  1000 GALLONS TRANSFERRED
     4-06-001-53  UNLOAD-JET FUEL          0.          0.         0.         0.45         0.  1000 GALLONS TRANSFERRED
     4-06-001-54  UNLOAD-KEROSENE          0.          0.         0.         0.23         0.  1000 GALLONS TRANSFERRED
     4-06-001-55  UNLOAD-DIST OIL          0.          0.         0.         0.24         0.  1000 GALLONS TRANSFERRED
     4-06-001-97  LOAD(SPLSH)SPECFY                                                          1000 GALLONS TRANSFERRED
     4-06-001-98  LOAD(SUBM)SPECIFY                                                          1000 GALLONS TRANSFERRED
     4-06-001-99  UNLOAD-SPECIFY                                                             1000 GALLONS TRANSFERRED

  MARINE VESSELS

     4-06-002-01  LOADING-GASOLINE         0.          0.         0.         2.88         0.  1000 GALLONS TRANSFERRED
     4-06-002-02  LOADING-CRUDE OIL        0.          0.         0.         2.59         0.  1000 GALLONS TRANSFERRED
     4-06-002-03  LOADING-JET FUEL         0.          0.         0.         0.60         0.  1000 GALLONS TRANSFERRED
     4-06-002-04  LOADING-KEROSENE         0.          0.         0.         0.27         0.  1000 GALLONS TRANSFERRED
     4-06-002-05  LOADING-DIST OIL         0.          0.         0.         0.29         0.  1000 GALLONS TRANSFERRED
     4-06-002-26  UNLOAD-GASOLINE          0.          0.         0.         2.52         0.  1000 GALLONS TRANSFERRED
     4-06-002-27  UNLOAD-CRUDE OIL         0.          0.         0.         2.25         0.  1000 GALLONS TRANSFERRED
     4-06-002-28  UNLOAD-JET FUEL          0.          0.         0.         0.52         0.  1000 GALLONS TRANSFERRED
     4-06-002-29  UNLOAD-KEROSENE          0.          0.         0.         0.24         0.  1000 GALLONS TRANSFERRED
     4-06-002-30  UNLOAD-DIST OIL          0.          0.         0.         0.25         0.  1000 GALLONS TRANSFERRED
     4-06-002-98  LOADING-SPECIFY                                                            1000 GALLONS TRANSFERRED
     4-06-002-99  UNLOAD-SPECIFY                                                             1000 GALLONS TRANSFERRED

  UNDERGRD GASO STG

     4-06-003-01   SPLASH LOADING          0.          0.         0.        11.5          0.  1000 GALLONS TRANSFERRED
     4-06-003-02   SUB LOAD-UNCONT         0.          0.         0.         7.30         0.  1000 GALLONS TRANSFERRED
     4-06-003-03   SUB LOAD-OPN SYS        0.          0.         0.         0.80         0.  1000 GALLONS TRANSFERRED
     4-06-003-04   SUB LOAD-CLS SYS        0.          0.         0.         0.          0.  1000 GALLONS TRANSFERRED
     4-06-003-05   UNLOADING               0.          0.         0.         1.00         0.  1000 GALLONS TRANSFERRED
     4-06-003-99  SPECIFY METHOD                                                             1000 GALLONS TRANSFERRED

  FILL VEH GAS TANK

     4-06-004-01   VAP DISP LOSS           0.          0.         0.        11.0          0.  1000 GALLONS PUMPED
     4-06-004-02   LIQ SPILL LOSS          0.          0.         0.         0.67         0.  1000 GALLONS PUMPED
     4-06-004-99  OTHER LOSS                                                                 1000 GALLONS PUMPED

POINT SC EVAP      -MISC HC EVAP
.................  .................


  OTHER/NOT CLASIFD

     4-90-999-99  SPECIFY IN REMARK                                                          TONS PROCESSED

SOLID WASTE        -GOVERNMENT
.................  .................


  MUNICIPAL INCIN

     5-01-001-01  MULTIPLE CHAMBER       30.0         2.50       2.00        1.50        35.0  TONS BURNED
     5-01-001-02  SINGLE CHAMBER         15.0         2.50       2.00       15.0         20.0  TONS BURNED

  OPEN BURNING DUMP

     5-01-002-01  GENERAL                16.0         1.00       6.00       30.0         85.0  TONS BURNED
     5-01-002-02  LANDSCAPE/PRUNING      17.0                    2.00       20.0         40.0  TONS BURNED
     5-01-002-03  JET FUEL                                                                     HUNDREDS OF GALLONS

  INCINERATOR

     5-01-005-05  PATHOLOGICAL            8.00         0.        3.00        0.           0.  TONS BURNED
     5-01-005-06  SLUDGE                100.          1.00       5.00        1.00         0.  TONS DRY SLUDGE
     5-01-005-07  CONICAL                20.0         2.00       5.00       20.0         60.0  TONS BURNED
     5-01-005-99  OTHER/NOT CLASIFD                                                           TONS BURNED

  AUX.FUEL/NO EMSNS

     5-01-900-04  RESIDUAL OIL             0.          0.         0.         0.           0.  1000 GALLONS
     5-01-900-05  DISTILLATE OIL           0.          0.         0.         0.           0.  1000 GALLONS
     5-01-900-06  NATURAL GAS              0.          0.         0.         0.           0.  MILLION CUBIC FEET
     5-01-900-10  LPG                      0.          0.         0.         0.           0.  1000 GALLONS
     5-01-900-97  OTHER/NOT CLASIFD        0.          0.         0.         0.           0.  MILLION CUBIC FEET
     5-01-900-98  OTHER/NOT CLASIFD        0.          0.         0.         0.           0.  1000 GALLONS
     5-01-900-99  OTHER/NOT CLASIFD        0.          0.         0.         0.           0.  TONS

'A' INDICATES THE ASH CONTENT, 'S' INDICATES THE SULFUR CONTENT OF THE FUEL ON A PERCENT BASIS (BY WEIGHT)
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                              NATIONAL EMISSION DATA SYSTEM
                             SOURCE CLASSIFICATION CODES

                                  POUNDS EMITTED PER UNIT
SOLID WASTE       -COMM-INST               PART       SOX        NOX        HC         CO       U N I T S
****************  ****************

  INCINERATOR GEN

    5-02-001-01  MULTIPLE CHAMBER         7.00       2.50       3.00       3.00       10.0   TONS BURNED
    5-02-001-02  SINGLE CHAMBER          15.0        2.50       2.00      15.0        20.0   TONS BURNED
    5-02-001-03  CONTROLLED AIR           1.40       1.50      10.0        0.          0.    TONS BURNED
    5-02-001-04  CONICAL-REFUSE          20.0        2.00       5.00      20.0        60.0   TONS BURNED
    5-02-001-05  CONICAL-WOOD             7.00       0.10       1.00      11.0       130.    TONS BURNED

  OPEN BURNING

    5-02-002-01  WOOD                    17.0                   2.00       4.00       50.0   TONS BURNED
    5-02-002-02  REFUSE                                                                      TONS BURNED

  APARTMENT INCIN

    5-02-003-01  FLUE FED                30.0        0.50       3.00      15.0        20.0   TONS BURNED
    5-02-003-02  FLUE FED-MODIFIED        6.00       0.50      10.0        3.00       10.0   TONS BURNED

  INCINERATOR

    5-02-005-05  PATHOLOGICAL             8.00       0.         3.00       0.          0.    TONS BURNED
    5-02-005-06  SLUDGE                 100.         1.00       5.00       1.00        0.    TONS DRY SLUDGE
    5-02-005-99  OTHER/NOT CLASIFD                                                           TONS BURNED

  AUX.FUEL/NO EMSNS

    5-02-900-04  RESIDUAL OIL             0.         0.         0.         0.          0.    1000 GALLONS
    5-02-900-05  DISTILLATE OIL           0.         0.         0.         0.          0.    1000 GALLONS
    5-02-900-06  NATURAL GAS              0.         0.         0.         0.          0.    MILLION CUBIC FEET
    5-02-900-10  LPG                      0.         0.         0.         0.          0.    1000 GALLONS
    5-02-900-97  OTHER/NOT CLASIFD        0.         0.         0.         0.          0.    MILLION CUBIC FEET
    5-02-900-98  OTHER/NOT CLASIFD        0.         0.         0.         0.          0.    1000 GALLONS
    5-02-900-99  OTHER/NOT CLASIFD        0.         0.         0.         0.          0.    TONS
SOLID WASTE       -INDUSTRIAL
****************  ****************


  INCINERATOR

    5-03-001-01  MULTIPLE CHAMBER         7.00       2.50       3.00       3.00       10.0   TONS BURNED
    5-03-001-02  SINGLE CHAMBER          15.0        2.50       2.00      15.0        20.0   TONS BURNED
    5-03-001-03  CONTROLLED AIR           1.40       1.50      10.0        0.          0.    TONS BURNED
    5-03-001-04  CONICAL REFUSE          20.0        2.00       5.00      20.0        60.0   TONS BURNED
    5-03-001-05  CONICAL WOOD             7.00       0.10       1.00      11.0       130.    TONS BURNED
    5-03-001-06  OPEN PIT                13.0        0.10       4.00       0.          0.    TONS OF WASTE
  OPEN BURNING

    5-03-002-01  WOOD                    17.0        0.         2.00       4.00       50.0   TONS BURNED
    5-03-002-02  REFUSE                  16.0        1.00       6.00      30.0        85.0   TONS BURNED
    5-03-002-03  AUTO BODY COMPTS       100.         0.         4.00      30.0       125.    TONS BURNED
    5-03-002-04  COAL REFUSE PILES        0.90       1.10       0.10       0.50        2.50  CUBIC YARDS OF PILE
  AUTO BODY INCINAT

    5-03-003-01  W/O AFTERBURNER          2.00                  0.10       0.50        2.50  AUTOS BURNED
    5-03-003-02  W/ AFTERBURNER           1.50                  0.02       0.          0.    AUTOS BURNED
  RAIL CAR BURNING

    5-03-004-01  OPEN                                                                        CARS BURNED

  INCINERATOR

    5-03-005-06  SLUDGE                 100.         1.00       5.00       1.00        0.    TONS DRY SLUDGE
    5-03-005-99  OTHER/NOT CLASIFD                                                           TONS BURNED
  AUX.FUEL/NO EMSNS

    5-03-900-04  RESIDUAL OIL             0.         0.         0.         0.          0.    1000 GALLONS
    5-03-900-05  DISTILLATE OIL           0.         0.         0.         0.          0.    1000 GALLONS
    5-03-900-06  NATURAL GAS              0.         0.         0.         0.          0.    MILLION CUBIC FEET
    5-03-900-07  PROCESS GAS              0.         0.         0.         0.          0.    MILLION CUBIC FEET
    5-03-900-10  L P G                    0.         0.         0.         0.          0.    1000 GALLONS
    5-03-900-97  OTHER/NOT CLASIFD        0.         0.         0.         0.          0.    MILLION CUBIC FEET
    5-03-900-98  OTHER/NOT CLASIFD        0.         0.         0.         0.          0.    1000 GALLONS
    5-03-900-99  OTHER/NOT CLASIFD        0.         0.         0.         0.          0.    TONS
MISCELLANEOUS     -FEDRL NONEMITTERS
****************  ****************

  OTHER/NOT CLASIFD

    6-01-999-98  SPECIFY IN REMARK
    6-01-999-99  SPECIFY IN REMARK                                                           INSTALLATIONS (EACH)
                                                                                             AREA/ACRES

'A' INDICATES THE ASH CONTENT, 'S' INDICATES THE SULFUR CONTENT OF THE FUEL ON A PERCENT BASIS (BY WEIGHT)
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455<

APPENDIX D
PROJECTED EMISSION FACTORS FOR HIGHWAY VEHICLES

prepared by
David S. Kircher,
Marcia E. Williams,
and Charles C. Masser

INTRODUCTION

In earlier editions of *Compilation of Air Pollutant Emission Factors* (AP-42), projected emission factors for highway vehicles were integrated with actual, measured emission factors. Measured emission factors are mean values arrived at through a testing program that involves a random statistical sample of in-use vehicles. Projected emission factors, on the other hand, are a conglomeration of measurements of emissions from prototype vehicles, best estimates based on applicable Federal standards, and, in some cases, outright educated guesses. In an attempt to make the user more aware of these differences, projected emission factors are separated from the main body of emission factors and presented as an appendix in this supplement to the report.

Measured emission estimates are updated annually at the conclusion of EPA's annual surveillance program. Projected emission factors, however, are updated when new data become available and not necessarily on a regular schedule. For several reasons, revisions to projected emission factors are likely to be necessary more frequently than on an annual basis. First, current legislation allows for limited time extensions for achieving the statutory motor vehicle emission standards. Second, Congressional action that would change the timetable for achieving these standards, the standards themselves, or both is likely in the future. Third, new data on catalyst-equipped (1975) automobiles are becoming available daily. As a result, the user of these data is encouraged to keep abreast of happenings likely to affect the data presented herein. Every attempt will be made to revise these data in a timely fashion when revisions become necessary.

This appendix contains mostly tables of data. Emission factor calculations are only briefly described because the more detailed discussion in Chapter 3 applies in nearly all cases. Any exceptions to this are noted. The reader is frequently referred to the text of Chapter 3; thus, it is recommended that a copy be close at hand.

Six vehicle categories encompassing all registered motor vehicles in use and projected to be in use on U.S. highways are dealt with in this appendix. The categories in order of presentation are:

1. Light-duty, gasoline-powered vehicles
2. Light-duty, gasoline-powered trucks
3. Light-duty, diesel-powered vehicles
4. Heavy-duty, gasoline-powered vehicles
5. Heavy-duty, diesel-powered vehicles
6. Motorcycles
7. All highway vehicles

456<

D.1 LIGHT-DUTY, GASOLINE-POWERED VEHICLES

D.1.1 General

This vehicle category represents passenger cars, a major source of ambient levels of carbon monoxide, hydrocarbons, and nitrogen oxides in many areas of the United States. The reader is encouraged to become familiar with section 3.1.2, which discusses light-duty gasoline-powered vehicles in greater detail, before using the data presented here.

D.1.2 CO, HC, NO_x Exhaust Emissions

The calculation of projected composite emission factors is limited in this presentation to the Federal Test Procedure (FTP) methodology (see section 3.1.2). The modal technique is not, generally, amenable to absolute emission projections. A user who wants to quantify the projected emissions over a specific driving sequence can apply the modal technique to the 1972 calendar as discussed in section 3.1.2. A ratio of the 1972 calendar year modal emissions to the 1972 calendar year FTP emissions can be obtained, and this ratio can be applied to a projected FTP value to adjust for the specific driving cycle of interest.

The calculation of composite emission factors for light-duty vehicles using the FTP procedure is given by:

$$e_{npstwx} = \sum_{i=n-12}^{n} c_{ipn}\, m_{in}\, v_{ips}\, z_{ipt}\, r_{iptwx} \qquad \text{(D1-1)}$$

where: e_{npstwx} = Composite emission factor in grams per mile (g/km) for calendar year (n), pollutant (p), average speed (s), ambient temperature (t), percentage cold operation (w), and percentage hot start operation (x)

c_{ipn} = The FTP mean emission factor for the i^{th} model year light-duty vehicles during calendar year (n) and for pollutant (p)

m_{in} = The fraction of annual travel by the i^{th} model year light-duty vehicles during calendar year (n)

v_{ips} = The speed correction factor for the i^{th} model year light-duty vehicles for pollutant (p), and average speed (s). This variable applies only to CO, HC, and NO_x.

z_{ipt} = The temperature correction for the i^{th} model year light-duty vehicles for pollutant (p) and ambient temperature (t)

r_{iptwx} = The hot/cold vehicle operation correction factor for the i^{th} model year light-duty vehicles for pollutant (p), ambient temperature (t), percentage cold operation (w), and percentage hot start operation (x).

The variable c_{ipn} is summarized in Tables D.1-1 through D.1-21, segregated by location (California, non-California, high altitude). The input m_{in} is described by example in Table D.1-22. The speed correction factors are presented in Tables D.1-23 and D.1-24.

The temperature correction and hot/cold vehicle operation correction factors, given in Table D.1-25, are separated into non-catalyst and catalyst correction factors. Catalyst correction factors should be applied for model years 1975-1977. For non-catalyst vehicles, the factors are the same as those presented in section 3.1.2.

For catalyst vehicles, emissions during the hot start phase of operation (vehicle start-up after a short–less than 1 hour–engine-off period) are greater than vehicle emissions during the hot stabilized phase. Therefore, the correction factor is a function of the percentage of cold operation, the percentage of hot start operation, and the ambient temperature(t).

$$r_{iptw} = \frac{w + (100\text{-}w)f(t)}{20 + 80\ f(t)} \qquad \text{Pre-1975 model years} \qquad \text{(D1-2)}$$

$$r_{iptwx} = \frac{w + x\ f(t) + (100\text{-}w\text{-}x)\ g(t)}{20 + 27\ f(t) + 53\ g(t)} \qquad \text{Post-1974 model years} \qquad \text{(D1-3)}$$

Table D.1-1. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES–EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1973 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1968	94.0	58.4	8.8	5.5	3.34	2.07
1968	67.6	42.0	6.8	4.2	4.32	2.68
1969	65.4	40.6	5.3	3.3	5.08	3.15
1970	56.0	34.8	5.3	3.3	4.35	2.70
1971	53.5	33.2	4.3	2.7	4.30	2.67
1972	39.0	24.2	3.5	2.2	4.55	2.83
1973	37.0	23.0	3.2	2.0	3.1	1.9
High altitude						
Pre-1968	143	88.8	12.0	7.5	2.0	1.2
1968	106	65.8	7.6	4.7	2.86	1.77
1969	101	62.7	6.6	4.1	2.93	1.82
1970	91.0	56.5	6.0	3.7	3.32	2.06
1971	84.0	52.2	5.7	3.5	2.74	1.70
1972	84.0	52.2	5.2	3.2	3.08	1.91
1973	80.0	49.7	4.7	2.9	3.1	1.93

Table D.1-2. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES–STATE OF CALIFORNIA ONLY–FOR CALENDAR YEAR 1973 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
California						
Pre-1966	94.0	58.4	8.8	5.5	3.34	2.07
1966	81.0	50.3	6.5	4.0	3.61	2.24
1967	81.0	50.3	6.5	4.0	3.61	2.24
1968	67.6	42.0	6.8	4.2	4.32	2.68
1969	65.4	40.6	5.3	3.3	5.08	3.15
1970	56.0	34.8	5.3	3.3	4.35	2.70
1971	53.5	33.2	4.3	2.7	3.83	2.38
1972	49.0	30.4	3.9	2.4	3.81	2.37
1973	37.0	23.0	3.2	2.0	3.1	1.9

Table D.1-3. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES–EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1974 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1968	95.0	59.0	8.9	5.5	3.34	2.07
1968	70.6	43.8	7.4	4.6	4.32	2.68
1969	68.4	42.5	5.8	3.6	5.08	3.15
1970	58.5	36.3	5.8	3.6	4.35	2.70
1971	56.0	34.8	4.7	2.9	4.30	2.67
1972	41.0	25.5	3.8	2.4	4.55	2.83
1973	39.0	24.2	3.5	2.2	3.3	2.0
1974	37.0	23.0	3.2	2.0	3.1	1.9
High altitude						
Pre-1968	145	90.0	12.1	7.5	2.0	1.2
1968	111	68.9	8.3	5.2	2.86	1.78
1969	106	65.8	7.2	4.5	2.93	1.82
1970	95.0	59.0	6.6	4.1	3.32	2.06
1971	88.0	54.6	6.2	3.9	2.74	1.70
1972	88.0	54.6	5.7	3.5	3.08	1.91
1973	84.0	52.2	5.2	3.2	3.3	2.05
1974	80.0	49.7	4.7	2.9	3.1	1.9

Table D.1-4. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES–STATE OF CALIFORNIA ONLY–FOR CALENDAR YEAR 1974 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
California						
Pre-1966	95.0	59.0	8.9	5.5	3.34	2.07
1966	82.0	50.9	7.1	4.4	3.61	2.24
1967	82.0	50.9	7.1	4.4	3.61	2.24
1968	70.6	43.8	7.4	4.6	4.32	2.68
1969	68.4	42.5	5.8	3.6	5.08	3.15
1970	58.5	36.3	5.8	3.6	4.35	2.70
1971	56.0	34.8	4.7	2.9	3.83	2.38
1972	51.0	31.7	4.2	2.6	3.81	2.37
1973	39.0	24.2	3.5	2.2	3.3	2.05
1974	37.0	23.0	3.2	2.0	2.0	1.2

Table D.1-5. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES–EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1975 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1968	96.0	59.6	9.0	5.6	3.34	2.07
1968	73.6	45.7	8.0	5.0	4.32	2.68
1969	71.4	44.3	6.3	3.9	5.08	3.15
1970	61.0	37.9	6.3	3.9	4.35	2.70
1971	58.5	36.3	5.1	3.2	4.30	2.67
1972	43.0	26.7	4.1	2.5	4.55	2.83
1973	41.0	25.5	3.8	2.4	3.5	2.2
1974	39.0	24.2	3.5	2.2	3.3	2.0
1975	9.0	5.6	1.0	0.6	3.1	1.9
High altitude						
Pre-1968	147	91.3	12.2	7.6	2.0	1.2
1968	116	72.0	9.0	5.6	2.86	1.78
1969	111	68.9	7.8	4.8	2.93	1.82
1970	99.0	61.5	7.2	4.5	3.32	2.06
1971	92.0	57.1	6.7	4.2	2.74	1.70
1972	92.0	57.1	6.2	3.9	3.08	1.91
1973	88.0	54.6	5.7	3.5	3.5	2.17
1974	84.0	52.2	5.2	3.2	3.3	2.05
1975	19.5	12.1	1.46	0.91	3.1	1.9

Table D.1-6. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES–STATE OF CALIFORNIA ONLY–FOR CALENDAR YEAR 1975 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
California						
Pre-1966	96.0	59.6	9.0	5.6	3.34	2.07
1966	83.0	51.5	7.7	4.8	3.61	2.24
1967	83.0	51.5	7.7	4.8	3.61	2.24
1968	73.6	45.7	8.0	5.0	4.32	2.68
1969	71.4	44.3	6.3	3.9	5.08	3.15
1970	61.0	37.9	6.3	3.9	4.35	2.70
1971	58.5	36.3	5.1	3.2	3.83	2.38
1972	53.0	32.9	4.5	2.8	3.81	2.37
1973	41.0	25.5	3.8	2.4	3.5	2.17
1974	39.0	24.2	3.5	2.2	2.06	1.28
1975	5.4	3.4	0.6	0.4	2.0	1.2

Table D.1-7. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES– EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1976 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1968	97.0	60.2	9.1	5.7	3.34	2.07
1968	76.6	47.6	8.6	5.3	4.32	2.86
1969	74.4	46.2	6.8	4.2	5.08	3.15
1970	63.5	39.4	6.8	4.2	4.35	2.70
1971	61.0	37.9	5.5	3.4	4.30	2.67
1972	45.0	27.9	4.4	2.7	4.55	2.83
1973	43.0	26.7	4.1	2.5	3.7	2.3
1974	41.0	25.5	3.8	2.4	3.5	2.2
1975	9.9	6.1	1.20	0.75	3.2	2.0
1976	9.0	5.6	1.0	0.6	3.1	1.9
High altitude						
Pre-1968	149	92.5	12.3	7.6	2.0	1.2
1968	121	75.1	9.7	6.0	2.86	1.78
1969	116	72.0	8.4	5.2	2.93	1.82
1970	103	64.0	7.8	4.8	3.32	2.06
1971	96.0	59.6	7.2	4.5	2.74	1.70
1972	96.0	59.6	6.7	4.2	3.08	1.91
1973	92.0	57.1	6.2	3.9	3.7	2.3
1974	88.0	54.6	5.7	3.5	3.5	2.2
1975	21.5	13.4	1.76	1.09	3.2	2.0
1976	19.5	12.1	1.46	0.91	3.1	1.9

Table D.1-8. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES– STATE OF CALIFORNIA ONLY–FOR CALENDAR YEAR 1976 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
California						
Pre-1966	97.0	60.2	9.1	5.7	3.34	2.07
1966	84.0	52.2	8.3	5.2	3.61	2.24
1967	84.0	52.2	8.3	5.2	3.61	2.24
1968	76.6	47.6	8.6	5.3	4.32	2.68
1969	74.4	46.2	6.8	4.2	5.08	3.15
1970	63.5	39.4	6.8	4.2	4.35	2.70
1971	61.0	37.9	5.5	3.4	3.83	2.37
1972	55.0	34.2	4.8	3.0	3.81	2.37
1973	43.0	26.7	4.1	2.5	3.7	2.30
1974	41.0	25.5	3.8	2.4	2.12	1.32
1975	5.9	3.7	0.7	0.4	2.06	1.28
1976	5.4	3.4	0.6	0.4	2.0	1.24

Table D.1-9. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES—EXCLUDING CALIFORNIA—FOR CALENDAR YEAR 1977 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1968	98.0	60.9	9.2	5.7	3.34	2.07
1968	79.6	49.4	9.2	5.7	4.32	2.68
1969	77.4	48.1	7.3	4.5	5.08	3.15
1970	66.0	41.0	7.3	4.5	4.35	2.70
1971	63.5	39.4	5.9	3.7	4.30	2.67
1972	47.0	29.2	4.7	2.9	4.55	2.83
1973	45.0	27.9	4.4	2.7	3.9	2.4
1974	43.0	26.7	4.1	2.5	3.7	2.3
1975	10.8	6.7	1.4	0.9	3.3	2.0
1976	9.9	6.1	1.2	0.7	3.2	2.0
1977	9.0	5.6	1.0	0.6	2.0	1.2
High altitude						
Pre-1968	151	93.8	12.4	7.7	2.0	1.2
1968	126	78.2	10.4	6.5	2.86	1.78
1969	121	75.1	9.0	5.6	2.93	1.82
1970	107	66.4	8.4	5.2	3.32	2.06
1971	100	62.1	7.7	4.8	2.74	1.70
1972	100	62.1	7.2	4.5	3.08	1.91
1973	96.0	59.6	6.7	4.2	3.9	2.4
1974	92.0	57.1	6.2	3.9	3.7	2.3
1975	23.5	14.6	2.06	1.28	3.3	2.0
1976	21.5	13.4	1.76	1.09	3.2	2.0
1977	9.0	5.6	1.0	0.6	2.0	1.2

Table D.1-10. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES—STATE OF CALIFORNIA ONLY—FOR CALENDAR YEAR 1977 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
California						
Pre-1966	98.0	60.9	9.2	5.7	3.34	2.07
1966	85.0	52.8	9.0	5.6	3.61	2.24
1967	85.0	52.8	9.0	5.6	3.61	2.24
1968	79.6	49.4	9.2	5.7	4.32	2.68
1969	77.4	48.1	7.3	4.5	5.08	3.15
1970	66.0	41.0	7.3	4.5	4.35	2.70
1971	63.5	39.4	5.9	3.7	3.83	2.38
1972	57.0	35.4	5.1	3.2	3.81	2.37
1973	45.0	27.9	4.4	2.7	3.9	2.4
1974	43.0	26.7	4.1	2.5	2.18	1.35
1975	6.5	4.0	0.8	0.5	2.12	1.32
1976	5.9	3.7	0.7	0.4	2.06	1.28
1977	5.4	3.4	0.6	0.4	1.5	0.93

Table D.1-11. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES–EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1978 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1968	99.0	61.5	9.3	5.8	3.34	2.07
1968	82.6	51.3	9.3	5.8	4.32	2.68
1969	80.4	49.9	7.8	4.8	5.08	3.15
1970	68.5	42.5	7.8	4.8	4.35	2.70
1971	66.0	41.0	6.3	3.9	4.30	2.67
1972	49.0	30.4	5.0	3.1	4.55	2.83
1973	47.0	29.2	4.7	2.9	4.1	2.5
1974	45.0	27.9	4.4	2.7	3.9	2.4
1975	11.7	7.3	1.6	1.0	3.4	2.1
1976	10.8	6.7	1.4	0.9	3.3	2.0
1977	9.9	6.1	1.2	0.7	2.06	1.3
1978	2.8	1.7	0.27	0.17	0.24	0.15
High altitude						
Pre-1968	153	95	12.5	7.8	2.0	1.2
1968	131	81.4	11.1	6.9	2.86	1.78
1969	126	78.2	9.6	6.0	2.93	1.82
1970	111	68.9	9.0	5.6	3.32	2.06
1971	104	64.6	8.2	5.1	2.74	1.70
1972	104	64.6	7.7	4.8	3.08	1.91
1973	100	62.1	7.2	4.5	4.1	2.5
1974	96.0	59.6	6.7	4.2	3.9	2.4
1975	25.5	15.8	2.36	1.47	3.4	2.1
1976	23.5	14.6	2.06	1.28	3.3	2.0
1977	9.9	6.1	1.2	0.6	2.06	1.3
1978	2.8	1.7	0.27	0.17	0.24	0.15

Table D.1-12. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES–STATE OF CALIFORNIA ONLY–FOR CALENDAR YEAR 1978 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
California						
Pre-1966	99.0	61.5	9.3	5.8	3.34	2.07
1966	85.0	52.8	9.0	5.6	3.61	2.24
1967	85.0	52.8	9.0	5.6	3.61	2.24
1968	82.6	51.3	9.3	5.8	4.32	2.68
1969	80.4	49.9	7.8	4.8	5.08	3.15
1970	68.5	42.5	7.8	4.8	4.35	2.70
1971	66.0	41.0	6.3	3.9	3.83	2.38
1972	59.0	36.6	5.4	3.4	3.81	2.37
1973	47.0	29.2	4.7	2.9	4.1	2.55
1974	45.0	27.9	4.4	2.7	2.24	1.39
1975	7.0	4.3	1.0	0.6	2.18	1.35
1976	6.5	4.0	0.8	0.5	2.12	1.32
1977	5.9	3.7	0.7	0.4	1.56	0.97
1978	2.8	1.7	0.27	0.17	0.24	0.15

Table D.1-13. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES–EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1979 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1968	99.0	61.5	9.3	5.8	3.34	2.07
1968	82.6	51.3	9.3	5.8	4.32	2.68
1969	83.4	51.8	8.3	5.2	5.08	3.15
1970	71.0	44.1	8.3	5.2	4.35	2.70
1971	68.5	42.5	6.7	4.2	4.30	2.67
1972	51.0	31.7	5.3	3.3	4.55	2.83
1973	49.0	30.4	5.0	3.1	4.3	2.7
1974	47.0	29.2	4.7	2.9	4.1	2.5
1975	12.6	7.8	1.8	1.1	3.5	2.2
1976	11.7	7.3	1.6	1.0	3.4	2.1
1977	10.8	6.7	1.4	0.9	2.12	1.32
1978	3.1	1.9	0.32	0.20	0.29	0.18
1979	2.8	1.7	0.27	0.17	0.24	0.15
High altitude						
Pre-1968	153	95.0	12.5	7.8	2.00	1.20
1968	131	81.4	11.1	6.9	2.86	1.78
1969	131	81.4	10.2	6.3	2.93	1.82
1970	115	71.4	9.6	6.0	3.32	2.06
1971	108	67.1	8.7	5.4	2.74	1.70
1972	108	67.1	8.2	5.1	3.08	1.91
1973	104	64.6	7.7	4.8	4.3	2.7
1974	100	62.1	7.2	4.5	4.1	2.5
1975	27.5	17.1	2.66	1.65	3.5	2.2
1976	25.5	15.8	2.36	1.47	3.4	2.1
1977	10.8	6.7	1.4	0.9	2.12	1.32
1978	3.1	1.9	0.32	0.20	0.29	0.18
1979	2.8	1.7	0.27	0.17	0.24	0.15

Table D.1-14. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES–STATE OF CALIFORNIA ONLY–FOR CALENDAR YEAR 1979 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
California						
1966	85.0	52.8	9.0	5.6	3.61	2.24
1967	85.0	52.8	9.0	5.6	3.61	2.24
1968	82.6	51.3	9.3	5.8	4.32	2.68
1969	83.4	51.8	8.3	5.2	5.08	3.15
1970	71.0	44.1	8.3	5.2	4.35	2.70
1971	68.5	42.5	6.7	4.2	3.83	2.38
1972	61.0	37.9	5.7	3.5	3.81	2.37
1973	49.0	30.4	5.0	3.1	4.30	2.70
1974	47.0	29.2	4.7	2.9	2.30	1.43
1975	7.6	4.7	1.1	0.7	2.24	1.39
1976	7.0	4.3	1.0	0.6	2.18	1.35
1977	6.5	4.0	0.8	0.5	1.62	1.01
1978	3.1	1.9	0.32	0.20	0.29	0.18
1979	2.8	1.7	0.27	0.17	0.24	0.15

Table D.1-15. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES–EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1980 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1968	99.0	61.5	9.2	5.8	3.34	2.07
1968	82.6	51.3	9.3	5.8	4.32	2.68
1969	83.4	51.8	8.3	5.2	5.08	3.15
1970	73.5	45.6	8.8	5.5	4.35	2.70
1971	71.0	44.1	7.1	4.4	4.30	2.67
1972	53.0	32.9	5.6	3.5	4.55	2.83
1973	51.0	31.7	5.3	3.3	4.5	2.8
1974	49.0	30.4	5.0	3.1	4.3	2.7
1975	13.5	8.4	2.0	1.2	3.6	2.2
1976	12.6	7.8	1.8	1.1	3.5	2.2
1977	11.7	7.3	1.6	1.0	2.18	1.35
1978	3.4	2.1	0.38	0.24	0.34	0.21
1979	3.1	1.9	0.32	0.20	0.29	0.18
1980	2.8	1.7	0.27	0.17	0.24	0.15
High altitude						
Pre-1968	153	95.0	12.5	7.8	2.0	1.2
1968	131	81.4	11.1	6.9	2.86	1.78
1969	131	81.4	10.2	6.3	2.93	1.82
1970	119	73.9	10.2	6.3	3.32	2.06
1971	112	69.6	9.2	5.7	2.74	1.70
1972	112	69.6	8.7	5.4	3.08	1.91
1973	108	67.1	8.2	5.1	4.5	2.8
1974	104	64.6	7.7	4.8	4.3	2.7
1975	29.5	18.3	2.96	1.84	3.6	2.2
1976	27.5	17.1	2.66	1.65	3.5	2.2
1977	11.7	7.3	1.6	1.0	2.18	1.35
1978	3.4	2.1	0.38	0.24	0.34	0.21
1979	3.1	1.9	0.32	0.20	0.29	0.18
1980	2.8	1.7	0.27	0.17	0.24	0.15

Table D.1-16. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES–STATE OF CALIFORNIA ONLY–FOR CALENDAR YEAR 1980 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
California						
1967	85.0	52.8	9.0	5.6	3.61	2.24
1968	82.6	51.3	9.3	5.8	4.32	2.68
1969	83.4	51.8	8.3	5.2	5.08	3.15
1970	73.5	45.6	8.8	5.5	4.35	2.70
1971	71.0	44.1	7.1	4.4	3.83	2.38
1972	63.0	39.1	6.0	3.7	3.81	2.37
1973	51.0	31.7	5.3	3.3	4.50	2.79
1974	49.0	30.4	5.0	3.1	2.36	1.47
1975	8.1	5.0	1.2	0.7	2.30	1.43
1976	7.6	4.7	1.1	0.7	2.24	1.39
1977	7.0	4.3	1.0	0.6	1.68	1.04
1978	3.4	2.1	0.38	0.24	0.34	0.21
1979	3.1	1.9	0.32	0.20	0.29	0.18
1980	2.8	1.7	0.27	0.17	0.24	0.15

Table D.1-17. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES–EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1985 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
1972	57.0	35.4	6.2	3.9	4.55	2.83
1973	57.0	35.4	6.2	3.9	5.0	3.1
1974	57.0	35.4	6.2	3.9	5.0	3.1
1975	18.0	11.2	3.0	1.9	4.1	2.5
1976	17.1	10.6	2.8	1.7	4.0	2.5
1977	16.2	10.1	2.6	1.6	2.48	1.54
1978	4.8	3.0	0.65	0.40	1.1	0.68
1979	4.5	2.8	0.59	0.37	0.90	0.56
1980	4.2	2.6	0.54	0.34	0.73	0.45
1981	3.9	2.4	0.49	0.30	0.56	0.35
1982	3.6	2.2	0.43	0.27	0.40	0.25
1983	3.4	2.1	0.38	0.24	0.34	0.21
1984	3.1	1.9	0.32	0.20	0.29	0.18
1985	2.8	1.7	0.27	0.17	0.24	0.15
High altitude						
1972	120	74.5	9.7	6.0	3.08	1.91
1973	120	74.5	9.7	6.0	5.0	3.1
1974	120	74.5	9.7	6.0	5.0	3.1
1975	39.5	24.5	3.46	2.15	4.1	2.5
1976	37.5	23.3	3.16	1.96	4.0	2.5
1977	16.2	10.1	2.60	1.60	2.48	1.54
1978	4.8	3.0	0.65	0.40	1.00	0.68
1979	4.5	2.8	0.59	0.37	0.90	0.56
1980	4.2	2.6	0.54	0.34	0.73	0.45
1981	3.9	2.4	0.49	0.30	0.56	0.35
1982	3.6	2.2	0.43	0.27	0.40	0.25
1983	3.4	2.1	0.38	0.24	0.34	0.21
1984	3.1	1.9	0.32	0.20	0.29	0.18
1985	2.8	1.7	0.27	0.17	0.24	0.15

Table D.1-18. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES–STATE OF CALIFORNIA ONLY–FOR CALENDAR YEAR 1985 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
California						
1972	67.0	41.6	6.6	4.1	3.81	2.37
1973	57.0	35.4	6.2	3.9	5.0	3.1
1974	57.0	35.4	6.2	3.9	2.60	1.61
1975	10.8	6.7	1.8	1.1	2.60	1.61
1976	10.3	6.4	1.7	1.1	2.54	1.58
1977	9.7	6.0	1.6	1.0	1.98	1.23
1978	4.8	3.0	0.65	0.40	1.1	0.68
1979	4.5	2.8	0.59	0.37	0.90	0.56
1980	4.2	2.6	0.54	0.34	0.73	0.45
1981	3.9	2.4	0.49	0.30	0.56	0.35
1982	3.6	2.2	0.43	0.27	0.40	0.25
1983	3.4	2.1	0.38	0.24	0.34	0.21
1984	3.1	1.9	0.32	0.20	0.29	0.18
1985	2.8	1.7	0.27	0.17	0.24	0.15

Table D.1-19. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES—EXCLUDING CALIFORNIA—FOR CALENDAR YEAR 1990 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low and high altitude						
1977	18.0	11.2	3.0	1.9	2.6	1.6
1978	5.6	3.6	0.81	0.50	1.70	1.06
1979	5.6	3.6	0.81	0.50	1.70	1.06
1980	5.6	3.6	0.81	0.50	1.70	1.06
1981	5.3	3.3	0.76	0.47	1.50	0.93
1982	5.0	3.1	0.70	0.43	1.30	0.81
1983	4.8	3.0	0.65	0.40	1.10	0.68
1984	4.5	2.8	0.59	0.37	0.90	0.56
1985	4.2	2.6	0.54	0.34	0.73	0.45
1986	3.9	2.4	0.49	0.30	0.56	0.35
1987	3.6	2.2	0.43	0.27	0.40	0.25
1988	3.4	2.1	0.38	0.24	0.34	0.21
1989	3.1	1.9	0.32	0.20	0.29	0.18
1990	2.8	1.7	0.27	0.17	0.24	0.15

Table D.1-20. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES—STATE OF CALIFORNIA ONLY—FOR CALENDAR YEAR 1990 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
California						
1977	10.8	6.7	1.8	1.1	2.10	1.30
1978	5.6	3.5	0.81	0.50	1.70	1.06
1979	5.6	3.5	0.81	0.50	1.70	1.06
1980	5.6	3.5	0.81	0.50	1.70	1.06
1981	5.3	3.3	0.76	0.47	1.50	0.93
1982	5.0	3.1	0.70	0.43	1.30	0.81
1983	4.8	3.0	0.65	0.40	1.10	0.68
1984	4.5	2.8	0.59	0.37	0.90	0.56
1985	4.2	2.6	0.54	0.34	0.73	0.45
1986	3.9	2.4	0.49	0.30	0.56	0.35
1987	3.6	2.2	0.43	0.27	0.40	0.25
1988	3.4	2.1	0.38	0.24	0.34	0.21
1989	3.1	1.9	0.32	0.20	0.29	0.18
1990	2.8	1.7	0.27	0.17	0.24	0.15

Table D.1-21. PARTICULATE, SULFURIC ACID, AND TOTAL SULFUR OXIDES EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES

Pollutant	Emission factors Non-catalyst (Leaded fuel)	Non-catalyst (Unleaded fuel)	Catalyst (Unleaded fuel)
Particulate			
Exhaust[a]			
g/mi	0.34	0.05	0.05
g/km	0.21	0.03	0.03
Tire wear			
g/mi	0.20	0.20	0.20
g/km	0.12	0.12	0.12
Sulfuric acid			
g/mi	0.001	0.001	0.02-0.06[b]
g/km	0.001	0.001	0.01-0.04
Total sulfur oxides			
g/mi	0.13	0.13	0.13
g/km	0.08	0.08	0.08

[a] Excluding particulate sulfate or sulfuric acid aerosol.

[b] Sulfuric acid emission varies markedly with driving mode and fuel sulfur levels.

Table D.1-22. SAMPLE CALCULATION OF FRACTION OF ANNUAL LIGHT-DUTY VEHICLE TRAVEL BY MODEL YEAR[a]

Age, years	Fraction of total vehicles in use nationwide (a)[b]	Average annual miles driven (b)[c]	a x b	Fraction of annual travel (m)[d]
1	0.081	15,900	1,288	0.112
2	0.110	15,000	1,650	0.143
3	0.107	14,000	1,498	0.130
4	0.106	13,100	1,389	0.121
5	0.102	12,200	1,244	0.108
6	0.096	11,300	1,085	0.094
7	0.088	10,300	906	0.079
8	0.077	9,400	724	0.063
9	0.064	8,500	544	0.047
10	0.049	7,600	372	0.032
11	0.033	6,700	221	0.019
12	0.023	6,700	154	0.013
≥ 13	0.064	6,700	429	0.039

[a] References 1 through 6.

[b] These data are for July 1. Data from References 2-6 were averaged to produce a value for m that is better suited for projections.

[c] Mileage values are the results of at least squares analysis of data in Reference 1.

[d] $m = ab/\Sigma ab$.

Table D.1-23. COEFFICIENTS FOR SPEED CORRECTION FACTORS FOR LIGHT-DUTY VEHICLES[a,b]

Location	Model year	$v_{ips} = e^{(A + BS + CS^2)}$						$v_{ips} = A + BS$	
		Hydrocarbons			Carbon monoxide			Nitrogen oxides	
		A	B	C	A	B	C	A	B
Low altitude (Excluding 1966-1967 Calif.)	1957-1967	0.953	-6.00×10^{-2}	5.81×10^{-4}	0.967	-6.07×10^{-2}	5.78×10^{-4}	0.808	0.980×10^{-2}
California	1966-1967	0.957	-5.98×10^{-2}	5.63×10^{-4}	0.981	-6.22×10^{-2}	6.19×10^{-4}	0.844	0.798×10^{-2}
Low altitude	1968	1.070	-6.63×10^{-2}	5.98×10^{-4}	1.047	-6.52×10^{-2}	6.01×10^{-4}	0.888	0.569×10^{-2}
	1969	1.005	-6.27×10^{-2}	5.80×10^{-4}	1.259	-7.72×10^{-2}	6.60×10^{-4}	0.915	0.432×10^{-2}
	1970	0.901	-5.70×10^{-2}	5.59×10^{-4}	1.267	-7.72×10^{-2}	6.40×10^{-4}	0.843	0.798×10^{-2}
	Post-1970	0.943	-5.92×10^{-2}	5.67×10^{-4}	1.241	-7.52×10^{-2}	6.09×10^{-4}	0.843	0.804×10^{-2}
High altitude	1957-1967	0.883	-5.58×10^{-2}	5.52×10^{-4}	0.721	-4.57×10^{-2}	4.56×10^{-4}	0.602	2.027×10^{-2}
	1968	0.722	-4.63×10^{-2}	4.80×10^{-4}	0.662	-4.23×10^{-2}	4.33×10^{-4}	0.642	1.835×10^{-2}
	1969	0.706	-4.55×10^{-2}	4.84×10^{-4}	0.628	-4.04×10^{-2}	4.26×10^{-4}	0.726	1.403×10^{-2}
	1970	0.840	-5.33×10^{-2}	5.33×10^{-4}	0.835	-5.24×10^{-2}	4.98×10^{-4}	0.614	1.978×10^{-2}
	Post-1970	0.787	-4.99×10^{-2}	4.99×10^{-4}	0.894	-5.54×10^{-2}	4.99×10^{-4}	0.697	1.553×10^{-2}

[a] Reference 7. Equations should not be extended beyond the range of the data (15 to 45 mi/hr; 24 to 72 km/hr). For speed correction factors at low speeds (5 and 10 mi/hr; 8 and 16 km/hr) see Table D.1-24.

[b] The speed correction factor equations and coefficients presented in this table are expressed in terms of english units (miles per hour). In order to perform calculations using the metric system of units, it is suggested that kilometers per hour be first converted to miles per hour (1 km/hr = 0.621 mi/hr). Once speed correction factors are determined, all other calculations can be performed using metric units.

Table D.1-24. LOW AVERAGE SPEED CORRECTION FACTORS FOR LIGHT-DUTY VEHICLES[a]

Location	Model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
		5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)	5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)	5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)
Low altitude (Excluding 1966-1967 Calif.)	1957-1967	2.72	1.57	2.50	1.45	1.08	1.03
California	1966-1967	1.79	1.00	1.87	1.12	1.16	1.09
Low altitude	1968	3.06	1.75	2.96	1.66	1.04	1.00
	1969	3.57	1.86	2.95	1.65	1.08	1.05
	1970	3.60	1.88	2.51	1.51	1.13	1.05
	Post-1970	4.15	2.23	2.75	1.63	1.15	1.03
High altitude	1957-1967	2.29	1.48	2.34	1.37	1.33	1.20
	1968	2.43	1.54	2.10	1.27	1.22	1.18
	1969	2.47	1.61	2.04	1.22	1.22	1.08
	1970	2.84	1.72	2.35	1.36	1.19	1.11
	Post-1970	3.00	1.83	2.17	1.35	1.06	1.02

[a] Driving patterns developed from CAPE-21 vehicle operation data (Reference 8) were input to the modal emission analysis model (see section 3.1.2.3). The results predicted by the model (emissions at 5 and 10 mi/hr: 8 and 16 km/hr) were divided by FTP emission factors for hot operation to obtain the above results. The above data are approximate and represent the best currently available information.

Table D.1-25. LIGHT-DUTY VEHICLE TEMPERATURE CORRECTION FACTORS AND HOT/COLD VEHICLE OPERATION CORRECTION FACTORS FOR FTP EMISSION FACTORS[a]

Pollutant and controls	Temperature correction factor (z_{ipt})[b]	Hot/cold vehicle operation correction factors	
		g(t)	f(t)
Carbon monoxide			
Non-catalyst	$-0.0127t + 1.95$	–	$0.0045t + 0.02$
Catalyst	$-0.0743t + 6.58$	$e^{0.035t - 5.24}$	$e^{0.036t - 4.14}$
Hydrocarbons			
Non-catalyst	$-0.0113t + 1.81$	–	$0.0079t + 0.03$
Catalyst	$-0.0304t + 3.25$	$0.0018t + 0.0095$	$0.0050t - 0.0409$
Nitrogen oxides			
Non-catalyst	$-0.0046t + 1.36$	–	$-0.0068t + 1.64$
Catalyst	$-0.0060t + 1.52$	$-0.0010t + 0.858$	$0.0010t + 0.835$

[a] Reference 9. Temperature (t) is expressed in °F. In order to apply the above equations, °C must first be converted to °F (F= 9/5C +32). Similarly °Kelvin (K) must be converted to °F (F= 9/5(K-273.16)+32).

[b] The formulae for z_{ipt} enable the correction of FTP emission factors for ambient temperature. The formulae for f(t) are used in conjunction with Equation D1-2 to calculate r_{iptw}. If the variable r_{iptw} is used in Equation D1-1, z_{ipt} must be used also.

where: f(t) and g(t) are given in Table D.1-25, w is the percentage of cold operation, and x is the percentage of hot start operation. For pre-1975 model year vehicles, non-catalyst factors should be used. For 1975-1977, catalyst factors should be used.

The use of catalysts after 1978 is uncertain at present. For model years 1979 and beyond, the use of those correction factors that produce the highest emission estimates is suggested in order that emissions are not underestimated. The extent of use of catalysts in 1977 and 1978 will depend on the impact of the 1979 sulfuric acid emission standard, which cannot now be predicted.

D.1.3 Crankcase and Evaporative Hydrocarbon Emission Factors

In addition to exhaust emission factors, the calculation of hydrocarbon emissions from gasoline motor vehicles involves evaporative and crankcase hydrocarbon emission factors. Composite crankcase emissions can be determined using:

$$f_n = \sum_{i=n-12}^{n} h_i m_{in} \qquad \text{(D1-4)}$$

where: f_n = The composite crankcase hydrocarbon emission factor for calendar year (n)

h_i = The crankcase emission factor for the i^{th} model year

m_{in} = The weighted annual travel of the i^{th} model year during calendar year (n)

Crankcase hydrocarbon emission factor by model year are summarized in Table D.1-26.

Table D. 1-26. CRANKCASE HYDROCARBON EMISSIONS BY MODEL YEAR FOR LIGHT-DUTY VEHICLES EMISSION FACTOR RATING: B

Model year	Hydrocarbons g/mi	Hydrocarbons g/km
California only		
Pre-1961	4.1	2.5
1961 through 1963	0.8	0.5
1964 through 1967	0.0	0.0
Post-1967	0.0	0.0
All areas except California		
Pre-1963	4.1	2.5
1963 through 1967	0.8	0.5
Post-1967	0.0	0.0

There are two sources of evaporative hydrocarbon emissions from light-duty vehicles: the fuel tank and the carburetor system. Diurnal changes in ambient temperature result in expansion of the air-fuel mixture in a partially filled fuel tank. As a result, gasoline vapor is expelled to the atmosphere. Running losses from the fuel tank occur as the fuel is heated by the road surface during driving, and hot soak losses from the carburetor system occur after engine shutdown at the end of a trip. Carburetor system losses occur from such locations as the carburetor vents, the float bowl, and the gaps around the throttle and choke shafts. Because evaporative emissions are a function of the diurnal variation in ambient temperature and the number of trips per day, emissions are best calculated in terms of evaporative emissions per day per vehicle. Emissions per day can be converted to emissions per mile (if necessary) by dividing the emissions per day be an average daily miles per vehicle value. This value is likely to vary from location to location, however. The composite evaporative hydrocarbon emission factor is given by:

$$e_n = \sum_{i=n-12}^{n} (g_i + k_i d)(m_{in}) \qquad \text{(D1-5)}$$

where: e_n = The composite evaporative hydrocarbon emission factor for calendar year (n) in lbs/day (g/day)

g_i = The diurnal evaporative hydrocarbon emission factor for model year (i) in lbs/day (g/day)

k_i = The hot soak evaporative emission factor in lbs/trip (g/trip) for the i^{th} model year

d = The number of daily trips per vehicle (3.3 trips/vehicle-day is the nationwide average)

m_{in} = The weighted annual travel of the i^{th} model year during calendar year (n)

The variables g_i and k_i are presented in Table D.1-27 by model year.

Table D.1-27. EVAPORATIVE HYDROCARBON EMISSIONS BY MODEL YEAR FOR LIGHT-DUTY VEHICLES[a]
EMISSION FACTOR RATING: A

Location and model year	By source[b] Diurnal, g/day	Hot soak, g/trip	g/day[c]	Composite g/mi	g/km
Low altitude					
Pre-1970	26.0	14.7	74.5	2.53	1.57
1970 (Calif.)	16.3	10.9	52.3	1.78	1.11
1970 (non-Calif.)	26.0	14.7	74.5	2.53	1.57
1971	16.3	10.9	52.3	1.78	1.11
1972-1979	12.1	12.0	51.7	1.76	1.09
Post-1979[d]	–	–	–	0.5	0.31
High altitude[e]					
Pre-1971	37.4	17.4	94.8	3.22	2.00
1971-1979	17.4	14.2	64.3	2.19	1.36
Post-1979[e]	–	–	–	0.5	0.31

[a] References 10 and 11.

[b] See text for explanation.

[c] Gram per day values are diurnal emissions plus hot soak emissions multiplied by the average number of trips per day. Nationwide data from References 1 and 2 indicate that the average vehicle is used for 3.3 trips per day. Gram/mile values were determined by dividing average g/day by the average nationwide travel per vehicle (29.4 mi/day) from Reference 2.

[d] Post-1979 evaporative emission factors are based on the assumption that existing technology can result in further control of evaporative hydrocarbons. A breakdown of post-1979 emissions by source (that is, diurnal and hot soak) is not available.

[e] Vehicles without evaporative control were not tested at high altitude. Values presented here are the product of the ratio of pre-1971 (low altitude) evaporative emissions to 1972 evaporative emissions and 1971-1972 high altitude emissions.

D.1.4 Particulate and Sulfur Oxide Emissions

Light-duty, gasoline-powered vehicles emit relatively small quantities of particulate and sulfur oxides in comparison with emission levels of the three pollutants discussed above. For this reason, average rather than composite emission factors should be sufficiently accurate for approximating particulate and sulfur oxide emissions from light-duty, gasoline-powered vehicles. Average emission factors for these pollutants are presented in Table D.1-21. No Federal standards for these two pollutants are presently in effect, although many areas do have opacity (antismoke) regulations applicable to motor vehicles.

Sulfuric acid emission from catalysts is presently receiving considerable attention. An emission standard for that pollutant is anticipated beginning in model year 1979.

D.1.5 Basic Assumptions

Light-duty vehicle emission standards. A critical assumption necessary in the calculation of projected composite emission rates is the timetable for implementation of future emission standards for light- duty vehicles. The timetable used for light-duty vehicles in this appendix is that which reflects current legislation and administrative actions as of April 1, 1975. This schedule is:

- For hydrocarbons – 1.5 g/mi (0.93 g/km) for 1975 through 1977 model years; 0.41 g/mi (0.25 g/km) for 1978 and later model years.
- For carbon monoxide – 15 g/mi (9.3 g/km) for 1975 through 1977 model years; 3.4 g/mi (2.1 g/km) for 1978 and later model years.
- For nitrogen oxides – 3.1 g/mi (1.9 g/km) for 1975 and 1976 model years; 2.0 g/mi (1.24 g/km) for the 1977 model year; 0.4 g/mi (0.25 g/km) for 1978 and later model years.

Although the statutory standards of 0.41 g/mi for HC, 3.4 g/mi for CO, and 0.4 g/mi for NO_x are legally scheduled for implementation in 1978, consideration of increased sulfuric acid emission from catalysts, fuel economy problems and control technology availability, and reevaluation of the level of NO_x control needed to achieve the NO_2 air quality standard led the EPA Administrator to recommend to Congress that the light-duty vehicle emission control schedule be revised. The tabulated values in this appendix do not, however, reflect these recent recommendations. If Congress accepts the proposed revisions, the appropriate tables will be revised.

Deterioration and emission factors. Although deterioration factors are no longer presented by themselves in this publication, they are, nonetheless, used implicitly to calculate calendar year emission factors for motor vehicles. Based on an analysis of surveillance data,[10,11] approximate linear deterioration rates for pre-1968 model years were established as follows: carbon monoxide – 1 percent per calendar year, hydrocarbons–1 percent per calendar year, and nitrogen oxides–0 percent per calendar year. For 1968-1974 model years, deterioration was assumed to be 5 percent per calendar year for CO, 10 percent per calendar year for HC, and 7 percent per calendar year for NO_x. For all pre-1975 model years, linear deterioration was applied to the surveillance test results to determine tabulated values.[11] Vehicles of model year 1975 and later are assumed to have a deterioration rate of 10 percent per calendar year for CO and 20 percent per calendar year for HC. For NO_x, see the following section on credit for inspection/maintenance systems. These deterioration rates are applied to new vehicle emission factors for prototype cars.

D.1.6 Credit for Inspection/Maintenance Systems

If an Air Quality Control Region has an inspection/maintenance (I/M) program, the following credits can be applied to light-duty vehicles:

1. A 10 percent reduction in CO and HC can be applied to all model year vehicles starting the year I/M is introduced.
2. Deterioration following the initial 10 percent is assumed to follow the schedules below:

	HC	CO
Pre-1975 vehicles	2 percent per year	2 percent per year
1975 and later vehicles	12 percent per year	7 percent per year

3. This deterioration rate continues until a vehicle is 10 years old and remains stable thereafter. No catalyst replacement is assumed.

4. The NO_x emission deterioration and response to I/M is highly conjectural; the estimates below are based on the assumption of engine-out emission of 1.2 g/mi at low mileage, deterioration of engine-out emission at 4 percent per year, NO_x catalyst efficiency deterioration from 80 percent to 70 percent in the first 3 years, and a linear deterioration in average catalyst efficiency from 70 percent to zero over the next 7 years because of catalyst failures. The response to I/M without catalyst replacement is a reduction in the engine-out deterioration from 4 to 2 percent per year. One catalyst replacement is assumed for the catalyst replacement scenario. Note: There is no emission reduction due to I/M for pre-1978 vehicles.

NO_x EMISSION DETERIORATION

(Standard is 0.4 g/mi, 0.25 g/km)

	No I/M		I/M, no catalyst replacement		I/M, one catalyst replacement	
Year	g/mi	g/km	g/mi	g/km	g/mi	g/km
1	0.24	0.15	0.24	0.15	0.24	0.15
2	0.29	0.18	0.28	0.17	0.28	0.17
3	0.34	0.21	0.33	0.20	0.33	0.20
4	0.40	0.25	0.38	0.24	0.38	0.24
5	0.56	0.35	0.52	0.32	0.39	0.24
6	0.73	0.45	0.66	0.41	0.40	0.25
7	0.90	0.56	0.81	0.50	0.47	0.29
8	1.1	0.68	0.96	0.60	0.55	0.34
9	1.3	0.81	1.12	0.70	0.63	0.39
10	1.5	0.93	1.3	0.81	0.71	0.44
> 10	1.7	1.1	1.5	0.93	0.80	0.50

[a] Table does not apply to pre-1978 vehicles.

D.1.7 Adjusting Emission Factor Tables for Changes in Future Light-Duty Vehicle Emission Standards

Because it is likely that Congressional action will alter the existing light-duty emission standard schedule, a methodology is presented here to enable modification of the emission factor tables (Tables D.1-1 through D.1-20). The emission factor tables presented in this appendix, as stated previously, reflect statutory carbon monoxide, hydrocarbon, and nitrogen oxides exhaust emission standards. If changes in the magnitude of the standards and/or the implementation dates occur, appropriate adjustments can be accomplished using Table D.1-28. This table contains emission factors by vehicle age for a number of likely future emission standards.

In order to illustrate the proper use of Table 1-28, the following hypothetical example is given. Emission standards applicable up to and including the 1977 model year are set by law, but changes in the schedule after 1977 (beginning with 1978 models) may occur. For purposes of this example, assume that the Congress changes the existing law such that 1978-1979 model year vehicles are subject to a carbon monoxide emission standard of 9.0 g/mi, a hydrocarbon emission standard of 0.9 g/mi, and a nitrogen oxides emission standard of 2.0 g/mi. Assume also that this scenario has no effect on 1980 and later models, which remain at present statutory levels.

Table D.1-28. EXHAUST EMISSION FACTORS BY VEHICLE AGE FOR SELECTED LIGHT-DUTY VEHICLE EMISSION STANDARDS

Vehicle age, years[a]	Carbon monoxide						Hydrocarbons						Nitrogen oxides							
	15.0 g/mi Standard		9.0 g/mi Standard		3.4 g/mi Standard		1.5 g/mi Standard		0.9 g/mi Standard		0.41 g/mi Standard		2.0 g/mi Standard		1.5 g/mi Standard		1.0 g/mi Standard		0.4 g/mi Standard	
	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km
1	9.0	5.6	5.4	3.4	2.8	1.7	1.0	0.6	0.6	0.4	0.27	0.17	2.00	1.2	1.50	0.93	1.0	0.6	0.24	0.15
2	9.9	6.1	5.9	3.7	3.1	1.9	1.2	0.7	0.7	0.4	0.32	0.20	2.06	1.28	1.56	0.97	1.04	0.65	0.29	0.18
3	10.8	6.7	6.5	4.0	3.4	2.1	1.4	0.9	0.8	0.5	0.38	0.24	2.12	1.32	1.62	1.01	1.08	0.67	0.34	0.21
4	11.7	7.3	7.0	4.3	3.6	2.2	1.6	1.0	1.0	0.6	0.43	0.27	2.18	1.35	1.68	1.04	1.12	0.70	0.40	0.25
5	12.6	7.8	7.6	4.7	3.9	2.4	1.8	1.1	1.1	0.7	0.49	0.30	2.24	1.39	1.74	1.08	1.16	0.72	0.56	0.35
6	13.5	8.4	8.1	5.0	4.2	2.6	2.0	1.2	1.2	0.7	0.54	0.34	2.30	1.43	1.80	1.12	1.20	0.75	0.73	0.45
7	14.4	8.9	8.6	5.3	4.5	2.8	2.2	1.4	1.3	0.8	0.59	0.37	2.36	1.47	1.86	1.16	1.24	0.77	0.90	0.56
8	15.3	9.5	9.2	5.7	4.8	3.0	2.4	1.5	1.4	0.9	0.65	0.40	2.42	1.50	1.92	1.19	1.28	0.79	1.1	0.68
9	16.2	10.1	9.7	6.0	5.0	3.1	2.6	1.6	1.6	1.0	0.70	0.43	2.48	1.54	1.98	1.23	1.32	0.82	1.3	0.81
10	17.1	10.6	10.3	6.4	5.3	3.3	2.8	1.7	1.7	1.1	0.76	0.47	2.54	1.58	2.04	1.27	1.36	0.84	1.5	0.93
11+	18.0	11.2	10.8	6.7	5.6	3.5	3.0	1.9	1.8	1.1	0.81	0.50	2.60	1.61	2.10	1.30	1.40	0.87	1.7	1.06

[a] Vehicle age refers to a year in a vehicle's life. For example, age one means vehicles from 0 to 1 year old.

This change in the standard schedule affects the tabulated values for the 1978 and 1979 model years presented in Tables D.1-11 through D.1-20. In other words, every number in every column in these tables headed with "1978 or 1979" model year must be completely changed. The appropriate replacement values are summarized in Table D.1-28. The age of the vehicle refers to a year in a vehicle's life. For example, the 1978 *model* year vehicles are assumed to be age one in *calendar* year 1978, age two in *calendar* year 1979 and so on.

To change the 1978 model year column in Table D.1-11 to reflect our hypothetical Congressional action, the appropriate values are extracted from the first *row* (age one) of Table D.1-28. For a 9.0 g/mi CO standard, the age one emission factor for both low and high altitude locations is 5.4 g/mi (3.4 g/km). This value is used to replace the existing value [2.8 g/mi (1.7 g/km)] in the 1978 column of Table D.1-11. A similar procedure is used for hydrocarbons and nitrogen oxides.

To illustrate a slightly more complicated situation, consider the revision of Table D.1-16 to reflect our hypothetical situation. All the values in the 1978 and 1979 columns must be changed. In 1980, the 1978 model year vehicles are age three, thus from Table D.1-28 the appropriate carbon monoxide emission factor is 6.5 g/mi (4.0 g/km). This value replaces the existing value of 3.4 g/mi (2.1 g/km). The 1979 model year carbon monoxide emission factor is 5.9 g/mi (3.7 g/km), replacing the existing Table D.1-16 value of 3.1 g/mi (1.9 g/km). This procedure is followed, using Table D.1-28, for all three pollutants. The procedure is similar for other standard schedules and other calendar year tables.

The above methodology was designed to enable the user of this document to quickly revise the tables. Any Congressional action will result in revision of the appropriate tables by EPA. Publication of these revised tables takes time, however, and although every effort is made by EPA to make these changes quickly, the required lead time is such that certain users may want to perform the modifications to the tables in advance. The standards covered in Table D.1-28 represent the most likely values Congress will adopt, but by no means represent all possible standards.

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D.2 LIGHT-DUTY, GASOLINE-POWERED TRUCKS

D.2.1 General

This class of vehicles includes all trucks with a gross vehicle weight (GVW) of 8500 lb (3856 kg) or less. It is comprised of vehicles that formerly were included in the light-duty truck (6000 lb: 2722 kg GVW and under) and the heavy-duty vehicle (6001 lb; 2722 kg GVW and over) classes. Generally, these trucks are used for personal transportation as opposed to commercial use.

D.2.2 FTP Exhaust Emissions

Projected emission factors for light trucks are summarized in Tables D.2-1 through D.2-12, (For information on projected emission factors for vehicles operated in California and at high altitude, see sections D.2.5 and D.2.6). The basic methodology used for projecting light-duty vehicle emission factors (section D.1 of this appendix) also applies to this class. As in section D.1, the composite emission factor for light-duty trucks is given by:

$$e_{npstwx} = \sum_{i=n-12}^{n} c_{ipn} m_{in} v_{ips} z_{ipt} r_{iptwx} \qquad (D2\text{-}1)$$

where: e_{npstwx} = Composite emission factor in g/mi (g/km) for calendar year (n), pollutant (p), average speed (s), ambient temperature (t), percentage cold operation (w), and percentage hot start operation (x)

c_{ipn} = The 1975 Federal Test Procedure mean emission factor for the i^{th} model year light-duty trucks during calendar year (n) and for pollutant (p)

m_{in} = The fraction of annual travel by the i^{th} model year light-duty trucks during calendar year (n)

v_{ips} = The speed correction factor for the i^{th} model year light-duty trucks for pollutant (p) and average speed (s)

z_{ipt} = The temperature correction for the i^{th} model year light-duty trucks for pollutant (p) and ambient temperature (t)

r_{iptwx} = The hot/cold vehicle operation correction factor for the i^{th} model year light-duty trucks for pollutant (p), ambient temperature (t), percentage cold operation (w), and percentage hot start operation (x)

Values for m_{in} are given in Table D.2-11. Unless other data are available, v_{ips} (Tables D.2-12 and D.2-13), z_{ipt}, and r_{iptwx} (Table D.2-14) are the same for this class as for light-duty vehicles.

Table D.2-1. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED TRUCKS– EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1973 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1968	125.0	77.6	17.0	10.6	4.2	2.6
1968	70.0	43.5	7.9	4.9	4.9	3.0
1969	67.8	42.1	5.9	3.7	5.3	3.3
1970	56.0	34.8	5.4	3.4	5.2	3.2
1971	56.0	34.8	4.7	2.9	5.2	3.2
1972	45.0	27.9	3.8	2.4	5.3	3.3
1973	42.8	26.6	3.6	2.2	4.4	2.7

Table D.2-2. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED TRUCKS EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1974 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1968	125.0	77.6	17.0	10.6	4.2	2.6
1968	73.5	45.6	8.7	5.4	4.9	3.0
1969	71.3	44.3	6.5	4.0	5.3	3.3
1970	58.5	36.3	6.0	3.7	5.2	3.2
1971	58.5	36.3	5.2	3.2	5.2	3.2
1972	47.2	29.3	4.2	2.6	5.3	3.3
1973	45.0	27.9	4.0	2.5	4.6	2.9
1974	42.8	26.6	3.6	2.2	4.4	2.7

Table D.2-3. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED TRUCKS–EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1975 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1968	125	77.6	17.0	10.6	4.2	2.6
1968	77.0	47.8	9.5	5.9	4.9	3.0
1969	74.8	46.5	7.1	4.4	5.3	3.3
1970	61.0	37.9	6.6	4.1	5.2	3.2
1971	61.0	37.9	5.7	3.5	5.2	3.2
1972	49.4	30.7	4.6	2.9	5.3	3.3
1973	47.2	29.3	4.4	2.7	4.8	3.0
1974	45.0	27.9	4.0	2.5	4.6	2.9
1975	27.0	16.8	2.7	1.7	4.4	2.7

Table D.2-4. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED TRUCKS–EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1976 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1968	125	77.6	17.0	10.6	4.2	2.6
1968	80.5	50.0	10.3	6.4	4.9	3.0
1969	78.3	48.6	7.7	4.8	5.3	3.3
1970	63.5	39.4	7.2	4.5	5.2	3.2
1971	63.5	39.4	6.2	3.9	5.2	3.2
1972	51.6	32.0	5.0	3.1	5.3	3.3
1973	49.4	30.7	4.8	3.0	5.0	3.1
1974	47.2	29.3	4.4	2.7	4.8	3.0
1975	28.5	17.7	3.0	1.9	4.6	2.9
1976	27.0	16.8	2.7	1.7	4.4	2.7

Table D.2-5. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED TRUCKS– EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1977 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1968	125	77.5	17.0	10.6	4.2	2.6
1968	84.0	52.2	11.1	6.9	4.9	3.0
1969	81.8	50.8	8.3	5.2	5.3	3.3
1970	66.0	41.0	7.8	4.8	5.2	3.2
1971	66.0	41.0	6.7	4.2	5.2	3.2
1972	53.8	33.4	5.4	3.4	5.3	3.3
1973	51.6	32.0	5.2	3.2	5.2	3.2
1974	49.4	30.7	4.8	3.0	5.0	3.1
1975	30.0	18.6	3.3	2.0	4.8	3.0
1976	28.5	17.7	3.0	1.9	4.6	2.9
1977	27.0	16.8	2.7	1.7	4.4	2.7

Table D.2-6. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED TRUCKS– EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1978

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1968	125	77.6	17.0	10.6	4.2	2.6
1968	87.5	54.3	11.9	7.4	4.9	3.0
1969	85.3	53.0	8.9	5.5	5.3	3.3
1970	68.5	42.5	8.4	5.2	5.2	3.2
1971	68.5	42.5	7.2	4.5	5.2	3.2
1972	56.0	34.8	5.8	3.6	5.3	3.3
1973	53.8	33.4	5.6	3.5	5.4	3.4
1974	51.6	32.0	5.2	3.2	5.2	3.2
1975	31.5	19.6	3.6	2.2	5.0	3.1
1976	30.0	18.6	3.3	2.0	4.8	3.0
1977	28.5	17.7	3.0	1.9	4.6	2.9
1978	9.8	6.1	1.0	0.6	2.3	1.4

Table D.2-7. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED TRUCKS–EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1979 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1968	125	77.6	17.0	10.6	4.2	2.6
1968	87.5	54.3	11.9	7.4	4.9	3.0
1969	88.8	55.1	9.5	5.9	5.3	3.3
1970	71.0	44.1	9.0	5.6	5.2	3.2
1971	71.0	44.1	7.7	4.8	5.2	3.2
1972	58.2	36.1	6.2	3.9	5.3	3.3
1973	56.0	34.8	6.0	3.7	5.6	3.5
1974	53.8	33.4	5.6	3.5	5.4	3.4
1975	33.0	20.5	3.9	2.4	5.2	3.2
1976	31.5	19.6	3.6	2.2	5.0	3.1
1977	30.0	18.6	3.3	1.4	4.8	3.0
1978	10.8	6.7	1.2	0.7	2.35	1.46
1979	9.8	6.1	1.0	0.6	2.3	1.4

Table D.2-8. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED TRUCKS–EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1980 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1968	125	77.6	17.0	10.6	4.2	2.6
1968	87.5	54.3	11.9	7.4	4.9	3.0
1969	88.8	55.1	9.5	5.9	5.3	3.3
1970	73.5	45.6	9.6	6.0	5.2	3.2
1971	73.5	45.6	8.2	5.1	5.2	3.2
1972	60.4	37.5	6.6	4.1	5.3	3.3
1973	58.2	36.1	6.4	4.0	5.8	3.6
1974	56.0	34.8	6.0	3.7	5.6	3.5
1975	34.5	21.4	4.2	2.6	5.4	3.4
1976	33.0	20.5	3.9	2.4	5.2	3.2
1977	31.5	19.6	3.6	2.2	5.0	3.1
1978	11.8	7.3	1.4	0.9	2.4	1.5
1979	10.8	6.7	1.2	0.7	2.35	1.46
1980	9.8	6.1	1.0	0.6	2.3	1.4

Table D.2-9. PROJECTED CARBON MONODIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED TRUCKS–EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1985 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
1972	64.8	40.2	7.4	4.6	5.3	3.3
1973	64.8	40.2	7.6	4.7	6.4	4.0
1974	64.8	40.2	7.6	4.7	6.4	4.0
1975	42.0	26.1	5.7	3.5	6.4	4.0
1976	40.5	25.1	5.4	3.4	6.2	3.9
1977	39.0	24.2	5.1	3.2	6.0	3.7
1978	16.8	10.4	2.4	1.5	2.65	1.65
1979	15.8	9.8	2.2	1.4	2.6	1.6
1980	14.8	9.2	2.0	1.2	2.55	1.58
1981	13.8	8.6	1.8	1.1	2.5	1.6
1982	12.8	7.9	1.6	1.0	2.45	1.52
1983	11.8	7.3	1.4	0.9	2.4	1.5
1984	10.8	6.7	1.2	0.7	2.35	1.46
1985	9.8	6.1	1.0	0.6	2.3	1.4

Table D.2-10. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED TRUCKS–EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1990 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
1977	42.0	26.1	5.7	3.5	6.4	4.0
1978	19.8	12.3	3.0	1.9	2.8	1.74
1979	19.8	12.3	3.0	1.9	2.8	1.74
1980	19.8	12.3	3.0	1.9	2.8	1.74
1981	18.8	11.7	2.8	1.7	2.75	1.71
1982	17.8	11.1	2.6	1.6	2.7	1.68
1983	16.8	10.4	2.4	1.5	2.65	1.65
1984	15.8	9.8	2.2	1.4	2.6	1.61
1985	14.8	9.2	2.0	1.2	2.55	1.58
1986	13.8	8.7	1.8	1.1	2.5	1.55
1987	12.8	7.9	1.6	1.0	2.45	1.52
1988	11.8	7.3	1.4	0.9	2.4	1.49
1989	10.8	6.7	1.2	0.7	2.35	1.46
1990	9.8	6.1	1.0	0.6	2.3	1.43

Table D.2-11. SAMPLE CALCULATION OF FRACTION OF ANNUAL LIGHT-DUTY, GASOLINE-POWERED TRUCK TRAVEL BY MODEL YEAR

Age, years	Fraction of total vehicles in use nationwide (a)[a]	Average annual miles driven (b)[b]	a x b	Fraction of annual travel (m)[c]
1	0.061	15,900	970	0.094
2	0.097	15,000	1,455	0.141
3	0.097	14,000	1,358	0.132
4	0.097	13,100	1,270	0.123
5	0.083	12,200	1,013	0.098
6	0.076	11,300	859	0.083
7	0.076	10,300	783	0.076
8	0.063	9,400	592	0.057
9	0.054	8,500	459	0.044
10	0.043	7,600	327	0.032
11	0.036	6,700	241	0.023
12	0.024	6,700	161	0.016
$\geq$13	0.185	4,500	832	0.081

[a] Vehicles in use by model year as of 1972 (Reference 1 and 2).

[b] Reference 2.

[c] $m = ab/\Sigma ab$.

Table D.2-12. COEFFICIENTS FOR SPEED CORRECTION FACTORS FOR LIGHT-DUTY TRUCKS[a]

Location	Model year	$v_{ips} = e^{(A + BS + CS^2)}$						$v_{ips} = A + BS$	
		Hydrocarbons			Carbon monoxide			Nitrogen oxides	
		A	B	C	A	B	C	A	B
Low altitude (Excluding 1966-1967 Calif.)	1957-1967	0.953	-6.00×10^{-2}	5.81×10^{-4}	0.967	-6.07×10^{-2}	5.78×10^{-4}	0.808	0.980×10^{-2}
California Low altitude	1966-1967	0.957	-5.98×10^{-2}	5.63×10^{-4}	0.981	-6.22×10^{-2}	6.19×10^{-4}	0.844	0.798×10^{-2}
	1968	1.070	-6.63×10^{-2}	5.98×10^{-4}	1.047	-6.52×10^{-2}	6.01×10^{-4}	0.888	0.569×10^{-2}
	1969	1.005	-6.27×10^{-2}	5.80×10^{-4}	1.259	-7.72×10^{-2}	6.60×10^{-4}	0.915	0.432×10^{-2}
	1970	0.901	-5.70×10^{-2}	5.59×10^{-4}	1.267	-7.72×10^{-2}	6.40×10^{-4}	0.843	0.798×10^{-2}
	Post-1970	0.943	-5.92×10^{-2}	5.67×10^{-4}	1.241	-7.52×10^{-2}	6.09×10^{-4}	0.843	0.804×10^{-2}
High altitude	1957-1967	0.883	-5.58×10^{-2}	5.52×10^{-4}	0.721	-4.57×10^{-2}	4.56×10^{-4}	0.602	2.027×10^{-2}
	1968	0.722	-4.63×10^{-2}	4.80×10^{-4}	0.662	-4.23×10^{-2}	4.33×10^{-4}	0.642	1.835×10^{-2}
	1969	0.706	-4.55×10^{-2}	4.84×10^{-4}	0.628	-4.04×10^{-2}	4.26×10^{-4}	0.726	1.403×10^{-2}
	1970	0.840	-5.33×10^{-2}	5.33×10^{-4}	0.835	-5.24×10^{-2}	4.98×10^{-4}	0.614	1.978×10^{-2}
	Post-1970	0.787	-4.99×10^{-2}	4.99×10^{-4}	0.894	-5.54×10^{-2}	4.99×10^{-4}	0.697	1.553×10^{-2}

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[a] Reference 3. Equations should not be extended beyond the range of data (15 to 45 mi/hr). These data are for light-duty vehicles and are assumed applicable to light-duty trucks.

Table D.2-13. LOW AVERAGE SPEED CORRECTION FACTORS FOR LIGHT-DUTY TRUCKS[a]

Location	Model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
		5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)	5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)	5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)
Low altitude (Excluding 1966-1967 Calif.)	1957-1967	2.72	1.57	2.50	1.45	1.08	1.03
California	1966-1967	1.79	1.00	1.87	1.12	1.16	1.09
Low altitude	1968	3.06	1.75	2.96	1.66	1.04	1.00
	1969	3.57	1.86	2.95	1.65	1.08	1.05
	1970	3.60	1.88	2.51	1.51	1.13	1.05
	Post-1970	4.15	2.23	2.75	1.63	1.15	1.03
High altitude	1957-1967	2.29	1.48	2.34	1.37	1.33	1.20
	1968	2.43	1.54	2.10	1.27	1.22	1.18
	1969	2.47	1.61	2.04	1.22	1.22	1.08
	1970	2.84	1.72	2.35	1.36	1.19	1.11
	Post-1970	3.00	1.83	2.17	1.35	1.06	1.02

[a] Driving patterns developed from CAPE-21 vehicle operation data (Reference 4) were input to the modal emission analysis model (see section 3.1.2.3). The results predicted by the model (emissions at 5 and 10 mi/hr (8 and 16 km/hr) were divided by FTP emission factors for operation to obtain the above results. The above data are approximate and represent the best currently available information.

Table D.2-14. LIGHT-DUTY TRUCK TEMPERATURE CORRECTION FACTORS AND HOT/COLD VEHICLE OPERATION CORRECTION FACTORS FOR FTP EMISSION FACTORS[a]

Pollutant and controls	Temperature correction factor (z_{ipt})[b]	Hot/cold vehicle operation correction factors	
		g(t)	f(t)
Carbon monoxide			
Non-catalyst	-0.0127t + 1.95	–	0.0045t + 0.02
Catalyst	-0.0743t + 6.58	$e^{0.035t} - 5.24$	$e^{0.036t} - 4.14$
Hydrocarbons			
Non-catalyst	-0.0113t + 1.81	–	0.0079t + 0.03
Catalyst	-0.0304t + 3.25	0.0018t + 0.0095	0.0050t – 0.0409
Nitrogen oxides			
Non-catalyst	-0.0046t + 1.36	–	-0.0068t + 1.64
Catalyst	-0.0060t + 1.52	-0.0010t + 0.858	0.0010t + 0.835

[a] Reference 5. Temperature (t) is expressed in °F. In order to apply the above equations, °C must first be converted to °F (F=9/5C + 32). Similarly °Kelvin (K) must be converted to °F (F= 9/5(K – 273.16) + 32).

[b] The formulae for z_{ipt} enable the correction of FTP emission factors for ambient temperature. The formulae for f(t) are used in conjunction with equation D.1-2 to calculate r_{ipwx}. If the variable r_{iptwx} is used in equation D.1-1, z_{ipt} must be used also. See section D1 for appropriate formulae for calculating r_{iptwx}.

For pre-1975 model year vehicles, noncatalyst temperature correction factors should be used. For 1975-1977 model year vehicles, temperature-dependent correction factors should be calculated for the catalyst and noncatalyst class, and the results weighted into an overall factor that is two-thirds catalyst, one-third noncatalyst. For 1978 and later model year vehicles, noncatalyst temperature correction factors should be applied.

D.2.3 Evaporative and Crankcase Emissions

In addition to exhaust emission factors, evaporative crankcase hydrocarbon emissions are determined using:

$$f_n = \sum_{i=n-12}^{n} h_i m_{in} \tag{D2-2}$$

where: f_n = The combined evaporative and crankcase hydrocarbon emission factor for calendar year (n)

h_i = The combined evaporative and crankcase hydrocarbon emission rate for the i^{th} model year. Emission factors for this source are reported in Table D.2-15. The crankcase and evaporative emissions reported in the table are added together to arrive at this variable.

m_{in} = The weighted annual travel of the i^{th} model year vehicle during calendar year (n)

Table D.2-15. CRANKCASE AND EVAPORATIVE HYDROCARBONS EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED TRUCKS

EMISSION FACTOR RATING: B

Location	Model years	Crankcase emissions[a]		Evaporative emissions[b]	
		g/km	g/mi	g/km	g/mi
All areas except high altitude and California[c]	Pre-1963	2.9	4.6	2.2	3.6
	1963-1967	1.5	2.4	2.2	3.6
	1968-1970	0.0	0.0	2.2	3.6
	1971	0.0	0.0	1.9	3.1
	1972-1979	0.0	0.0	1.9	3.1
	Post-1979[d]	0.0	0.0	0.3	0.5
High altitude	Pre-1963	2.9	4.6	2.9	4.6
	1963-1967	1.5	2.4	2.9	4.6
	1968-1970	0.0	0.0	2.9	4.6
	1971-1979	0.0	0.0	2.4	3.9
	Post-1979[d]	0.0	0.0	0.3	0.5

[a] Reference 6. Tabulated values were determined by assuming that two-thirds of the light-duty trucks are 6000 lbs GVW (2700 kg) and under, and that one-third are 6001-8500 lbs GVW (2700-3860 kg).

[b] Light-duty vehicle evaporative data (section 3.1.2) and heavy-duty vehicle evaporative data (section 3.1.4) were used to estimate the listed values.

[c] For California: Evaporative emissions for the 1970 model year are 1.9 g/km (3.1 g/mi) all other model years are the same as those reported as "All area except high altitude and California". Crankcase emissions for the pre-1961 California light-duty trucks are 4.6 g/mi (2.9 g/km), 1961-1963 model years are 2.4 (g/mi (1.5 g/km), all post-1963 model year vehicles are 0.0 g/mi (0.0 g/km).

[d] Post-1979 evaporative emission factors are based on the assumption that existing technology, when applied to the entire light truck class, can result in further control of evaporative hydrocarbons.

D.2.4 Particulate and Sulfur Oxides Emissions

Particulate and sulfur oxides emission factors are presented in Table D.2-16.

Table D.2-16. PARTICULATE, SULFURIC ACID, AND TOTAL SULFUR OXIDES EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES

Pollutant	Emission factors		
	Non-catalyst (Leaded fuel)	Non-catalyst (Unleaded fuel)	Catalyst (Unleaded fuel)
Particulate			
Exhaust[a]			
g/mi	0.34	0.05	0.05
g/km	0.21	0.03	0.03
Tire wear			
g/mi	0.20	0.20	0.20
g/km	0.12	0.12	0.12
Sulfuric acid			
g/mi	0.001	0.001	0.02-0.06[b]
g/km	0.001	0.001	0.01-0.04
Total sulfur oxides			
g/mi	0.18	0.18	0.18
g/km	0.11	0.11	0.11

[a] Excluding particulate sulfate or sulfuric acid aerosol.

[b] Sulfuric acid emission varies markedly with driving mode and fuel sulfur levels.

D.2.5 Basic Assumptions

Composition of class. For emission estimation purposes, this class is composed of trucks having a GVW of 8500 lb (3856 kg) or less. Thus, this class includes the group of trucks previously defined in AP-42 as light-duty vehicles (LDV) plus a group of vehicles previously defined as heavy-duty vehicles (HDV). On the basis of numbers of vehicles nationwide, the split is two-thirds LDVs, one-third HDVs.

Standards. The pollutant standards assumed for this category are weighted averages of the standards applicable to the various vehicle classes that were combined to create the light-duty truck class. Until 1975, those light-duty trucks that weighed 6000 lb (2722 kg) and under were required to meet light-duty vehicle emission standards. Beginning in 1975, in accordance with a court order, a separate light truck class was created. This class, which comprises two-thirds of the light-duty truck class (as defined here), is required to meet standards of 20 g/mi (12.4 g/km) of carbon monoxide, 2 g/mi (1.2 g/km) of hydrocarbons, and 3.1 g/mi (1.9 g/km) of nitrogen oxides from 1975 through 1977. The remaining one-third of the light-duty trucks are currently subject to heavy-duty vehicle standards. Data presented in section D.2 are based on the assumption that, beginning in 1978, the light-duty truck class of 0-8500 lb (3856 kg) GVW will be subject to the following standards: carbon monoxide–17.9 g/mi (11.1 g/km), hydrocarbon–1.65 g/mi (1.0 g/km), and nitrogen oxides–2.3 g/mi (1.4 g/km).

Deterioration. The same deterioration assumptions discussed in section D.1 for light-duty vehicles apply except that 1975-1977 model year vehicles weighing between 6000 and 8500 lb (2722-3856 kg) are assumed not to be equipped with catalytic converters. Therefore, the deterioration factors for light-duty trucks are weighted values composed of 6000-lb (2722 kg) GVW truck deterioration values and 6001 to 8500-lb (2722-3856 kg) GVW truck deterioration values. The weighting factors are two-thirds and one-third, respectively.

Actual emission values. For 1972 and earlier model year vehicles, emission values are those measured in the EPA Emission Surveillance Program[7,8] and the baseline study of 6,000- to 10,000-lb (2,722-4,536 kg) trucks.[9,10]

The tabulated values are weighted two-thirds for 0-6000-lb (0-2722 kg) trucks and one-third for 6000- to 8500-lb (2722-3856 kg) trucks. For 1973-1974 model year emission values, this same weighting factor is applied to projected 1973-1974 light-duty vehicle emissions and 1972 model year 6,000- to 10,000-lb (2,722-4,536 kg) emission values. 1975-1977 model year emission values for 0- to 6000-lb (0 to 2722 kg) GVW trucks are based on unpublished certification test data along with estimates of prototype-to-production differences. Post-1977 model year emission values are based on previous relationships of low mileage in-use emission values to the standards.

California values. Projected emission factors for vehicles operated in California were not computed because of a lack of information. The Pre-1975 California light-duty vehicle ratios can be applied to the light-duty trucks as a best estimate (see section D.1). For 1975 and later, no difference is expected except in the value for nitrogen oxides in 1975-1976; the California standards can be weighted two-thirds, and the truck baseline value of 7.1 g/mi (4.4 gm/km) one-third to get an estimated value for nitrogen oxides in 1975-1976.

D.2.6 High Altitude and Inspection/Maintenance Corrections

To correct for high altitude for all pollutants for light-duty trucks, the light-duty vehicle ratio of high altitude to low altitude emission factors for the model year vehicle is applied to the calendar year in question (see section D.1). Credit for inspection/maintenance for light-duty trucks is the same as that given for autos in section D.1. of this appendix.

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D.3 LIGHT-DUTY, DIESEL-POWERED VEHICLES

D.3.1 General

Although light-duty diesels represent only a small fraction of automobiles in use, their numbers can be expected to increase in the future. Currently, only two manufacturers produce diesel-powered automobiles for sale in the United States, but this may change as the demand for low polluting, economical engines grows.

D.3.2 Emissions

Because of the limited data base for these vehicles, no attempt has been made to predict deterioration factors. The composite emission factor calculation procedure involves only the Federal Test Procedure (FTP) emission factor and the fraction of travel by model year (see main text, section 3.1.3). The values presented in Table 3.1.3-1 apply to all model years and pollutants.

D.3.3 Basic Assumptions

Standards. See section D.1, Light-Duty, Gasoline-Powered Vehicles.

Deterioration. Because of the lack of data, no deterioration factors are assumed. Diesels are expected to continue to emit carbon monoxide and hydrocarbons at their present rates but to meet future NO_x standards exactly.

D.4 HEAVY-DUTY, GASOLINE-POWERED VEHICLES

D.4.1 General

This class includes vehicles with a gross vehicle weight of more than 8500 lb (3856 kg). Most of the vehicles are trucks; however, buses and special purpose vehicles such as motor homes are also included. As in other sections of this appendix the reader is encouraged to refer to the main text (see section 3.1.4) for a much more detailed presentation. The discussion presented here is brief, consisting primarily of data summaries.

D.4.2 Carbon Monoxide, Hydrocarbon, and Nitrogen Oxides Exhaust Emissions

The composite exhaust emission factor is calculated using:

$$e_{nps} = \sum_{i=n-12}^{n} c_{ipn} \, m_{in} \, v_{ips} \qquad \text{(D.4-1)}$$

where: e_{nps} = Composite emission factor in g/mi (g/km) for calendar year (n) pollutant (p), and average speed (s)

c_{ipn} = The test procedure emission factor for pollutant (p) in g/mi (g/km) for the i^{th} model year in calendar year (n)

m_{in} = The weighted annual travel of the i^{th} model year vehicles during calendar year (n). The determination of this variable involves the use of the vehicle year distribution.

v_{ips} = The speed correction factor for the i^{th} model year vehicles for pollutant (p) and average speed (s)

The projected test procedure emission factors (c_{ipn}) are summarized in Tables D.4-1 through D.4-10. These projected factors are based on the San Antonio Road Route test (see section 3.1.4) and assume 100 percent warmed-up vehicle operation at an average speed of approximately 18 mi/hr (29 km/hr). Table D.4-11 contains a sample calculation of the variable m_{in}, using nationwide statistics. Speed correction factor data are contained in Table D.4-12 and Table D.4-13.

Table D.4-1. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR HEAVY-DUTY, GASOLINE-POWERED VEHICLES– EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1973

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1970	238	148	35.4	22.0	6.8	4.2
1970	188	117	13.9	8.6	12.7	7.9
1971	188	117	13.8	8.6	12.6	7.8
1972	188	117	13.7	8.5	12.6	7.8
1973	188	117	13.6	8.4	12.5	7.8

Table D.4-2. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR HEAVY-DUTY, GASOLINE-POWERED VEHICLES–EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1974

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1970	238	148	35.4	22.0	6.8	4.2
1970	188	117	14.0	8.7	12.7	7.9
1971	188	117	13.9	8.6	12.7	7.9
1972	188	117	13.8	8.6	12.6	7.8
1973	188	117	13.7	8.5	12.6	7.8
1974	167	104	13.1	8.1	12.5	7.8

Table D.4-3. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR HEAVY-DUTY, GASOLINE-POWERED VEHICLES–EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1975

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1970	238	148	35.4	22.0	6.8	4.2
1970	188	117	14.1	8.8	12.8	7.9
1971	188	117	14.0	8.7	12.7	7.9
1972	188	117	13.9	8.6	12.7	7.9
1973	188	117	13.8	8.6	12.6	7.8
1974	168	104	13.2	8.2	12.6	7.8
1975	167	104	13.1	8.1	12.5	7.8

Table D.4-4. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR HEAVY-DUTY, GASOLINE-POWERED VEHICLES–EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1976

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1970	238	148	35.4	22.0	6.8	4.2
1970	188	117	14.2	8.8	12.8	7.9
1971	188	117	14.1	8.8	12.8	7.9
1972	188	117	14.0	8.7	12.7	7.9
1973	188	117	13.9	8.6	12.7	7.9
1974	169	105	13.3	8.3	12.6	7.8
1975	168	104	13.2	8.2	12.6	7.8
1976	167	104	13.1	8.1	12.5	7.8

Table D.4-5. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR HEAVY-DUTY, GASOLINE-POWERED VEHICLES—EXCLUDING CALIFORNIA—FOR CALENDAR YEAR 1977

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1970	238	148	35.4	22.0	6.8	4.2
1970	188	117	14.3	8.9	12.9	8.0
1971	188	117	14.2	8.8	12.8	7.9
1972	188	117	14.1	8.8	12.8	7.9
1973	188	117	14.0	8.7	12.7	7.9
1974	170	106	13.4	8.3	12.7	7.9
1975	169	105	13.3	8.3	12.6	7.8
1976	168	104	13.2	8.2	12.6	7.8
1977	167	104	13.1	8.1	12.5	7.8

Table D.4-6. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR HEAVY-DUTY, GASOLINE-POWERED VEHICLES—EXCLUDING CALIFORNIA—FOR CALENDAR YEAR 1978

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1970	238	148	35.4	22.0	6.8	4.2
1970	188	117	14.4	8.9	12.9	8.0
1971	188	117	14.3	8.9	12.9	8.0
1972	188	117	14.2	8.8	12.8	7.9
1973	188	117	14.1	8.8	12.8	7.9
1974	171	106	13.5	8.4	12.7	7.9
1975	170	106	13.4	8.3	12.7	7.9
1976	169	105	13.3	8.3	12.6	7.8
1977	168	104	13.2	8.2	12.6	7.8
1978	117	73	6.0	3.7	11.4	7.1

Table D.4-7. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR HEAVY-DUTY, GASOLINE-POWERED VEHICLES–EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1979

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1970	238	148	35.4	22.0	6.8	4.2
1970	188	117	14.4	8.9	13.0	8.1
1971	188	117	14.4	8.9	12.9	8.0
1972	188	117	14.3	8.9	12.9	8.0
1973	188	117	14.2	8.8	12.8	7.9
1974	172	107	13.6	8.4	12.8	7.9
1975	171	106	13.5	8.4	12.7	7.9
1976	170	106	13.4	8.3	12.7	7.9
1977	169	105	13.3	8.3	12.6	7.8
1978	118	73	6.0	3.7	11.6	7.2
1979	117	73	6.0	3.7	11.4	7.1

Table D.4-8. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR HEAVY-DUTY, GASOLINE-POWERED VEHICLES–EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1980

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1970	238	148	35.4	22.0	6.8	4.2
1970	188	117	14.4	8.9	13.0	8.1
1971	188	117	14.4	8.9	13.0	8.1
1972	188	117	14.4	8.9	12.9	8.0
1973	188	117	14.3	8.9	12.9	8.0
1974	173	107	13.7	8.5	12.8	7.9
1975	172	107	13.6	8.4	12.8	7.9
1976	171	106	13.5	8.4	12.7	7.9
1977	170	106	13.4	8.3	12.7	7.9
1978	119	74	6.1	3.8	11.8	7.3
1979	118	73	6.0	3.7	11.6	7.2
1980	117	73	6.0	3.7	11.4	7.1

Table D.4-9. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR HEAVY-DUTY, GASOLINE-POWERED VEHICLES– EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1985

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
1972	188	117	14.4	8.9	13.0	8.1
1973	188	117	14.4	8.9	13.0	8.1
1974	176	109	14.0	8.7	13.0	8.1
1975	176	109	14.0	8.7	13.0	8.1
1976	175	109	14.0	8.7	12.9	8.0
1977	174	108	13.9	8.6	12.9	8.0
1978	124	77	6.3	3.9	12.8	7.9
1979	123	76	6.2	3.9	12.6	7.8
1980	122	76	6.2	3.9	12.4	7.7
1981	121	75	6.2	3.9	12.2	7.6
1982	120	75	6.1	3.8	12.0	7.5
1983	119	74	6.1	3.8	11.8	7.3
1984	118	73	6.1	3.8	11.6	7.2
1985	117	73	6.0	3.7	11.4	7.1

Table D.4-10. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR HEAVY-DUTY, GASOLINE-POWERED VEHICLES– EXCLUDING CALIFORNIA–FOR CALENDAR YEAR 1990

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
1977	176	109	14.0	8.7	13.0	8.1
1978	126	78	6.3	3.9	13.0	8.1
1979	126	78	6.3	3.9	13.0	8.1
1980	126	78	6.2	3.9	13.0	8.1
1981	126	78	6.2	3.9	13.0	8.1
1982	125	78	6.2	3.9	13.0	8.1
1983	124	77	6.2	3.9	12.8	7.9
1984	123	76	6.2	3.9	12.6	7.8
1985	122	76	6.2	3.9	12.4	7.7
1986	121	75	6.1	3.8	12.2	7.6
1987	120	75	6.1	3.8	12.0	7.5
1988	119	74	6.1	3.8	11.8	7.3
1989	118	73	6.0	3.7	11.6	7.3
1990	117	73	6.0	3.7	11.4	7.1

494

Table D.4-11. SAMPLE CALCULATION OF FRACTION OF ANNUAL HEAVY-DUTY, GASOLINE-POWERED VEHICLE TRAVEL BY MODEL YEAR

Age, years	Fraction of total vehicles in use nationwide (a)[a]	Average annual miles driven (b)[b]	a x b	Fraction of annual travel (m)[c]
1	0.037	19,000	703	0.062
2	0.078	18,000	1,404	0.124
3	0.078	17,000	1,326	0.117
4	0.078	16,000	1,248	0.110
5	0.075	14,000	1,050	0.093
6	0.075	12,000	900	0.080
7	0.075	10,000	750	0.066
8	0.068	9,500	646	0.057
9	0.059	9,000	531	0.047
10	0.053	8,500	451	0.040
11	0.044	8,000	352	0.031
12	0.032	7,500	240	0.021
$\geq$13	0.247	7,000	1,729	0.153

[a] Vehicles in use by model year as of 1972 (Reference 1).

[b] Reference 1.

[c] $m = ab/\Sigma ab$.

Table D.4-12. COEFFICIENTS FOR SPEED CORRECTION FACTORS FOR HEAVY-DUTY, GASOLINE-POWERED VEHICLES[a,b]

Location	Model year	$v_{ips} = e^{(A + BS + CS^2)}$						$v_{ips} = A + BS$	
		Hydrocarbons			Carbon monoxide			Nitrogen oxides	
		A	B	C	A	B	C	A	B
Low altitude	Pre-1970	0.953	-6.00×10^{-2}	5.81×10^{-4}	0.967	-6.07×10^{-2}	5.78×10^{-4}	0.808	0.980×10^{-2}
	Post-1969	1.070	-6.63×10^{-2}	5.98×10^{-4}	1.047	-6.52×10^{-2}	6.01×10^{-4}	0.888	0.569×10^{-2}
High altitude	Pre-1970	0.883	-5.58×10^{-2}	5.52×10^{-4}	0.721	-4.57×10^{-2}	4.56×10^{-4}	0.602	2.027×10^{-2}
	Post-1969	0.722	-4.63×10^{-2}	4.80×10^{-4}	0.662	-4.23×10^{-2}	4.33×10^{-4}	0.642	1.835×10^{-2}

[a] Reference 2. Equations should not be extended beyond the range of data (15 to 45 mi/hr). These data are from tests of light-duty vehicles and are assumed applicable to heavy-duty vehicles.

[b] Speed (s) is in miles per hour (1 mi/hr = 1.61 km/hr).

Table D.4-13. LOW AVERAGE SPEED CORRECTION FACTORS FOR HEAVY-DUTY, GASOLINE-POWERED VEHICLES[a]

Location	Model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
		5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)	5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)	5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)
Low altitude	Pre-1970	2.72	1.57	2.50	1.45	1.08	1.03
	Post-1969	3.06	1.75	2.96	1.66	1.04	1.00
High altitude	Pre-1970	2.29	1.48	2.34	1.37	1.33	1.20
	Post-1969	2.43	1.54	2.10	1.27	1.22	1.18

[a] Driving patterns developed from CAPE-21 vehicle operation data (Reference 3) were input to the modal emission analysis model (see section 3.1.2.3). The results predicted by the model (emissions at 8 and 16 km/hr; 5 and 10 mi/hr) were divided by FTP emission factors for hot operation to obtain the above results. The above data represent the best currently available information for light-duty vehicles. These data are assumed applicable to heavy-duty vehicles given the lack of better information.

D.4.3 Crankcase and Evaporative Hydrocarbons

In addition to exhaust emission factors, the calculation of evaporative and crankcase hydrocarbon emissions are determined using:

$$f_n = \sum_{i=n-12}^{n} h_i m_{in} \qquad \text{(D.4-2)}$$

where: f_n = The combined evaporative and crankcase hydrocarbon emission factor for calendar year (n)

h_i = The combined evaporative and crankcase hydrocarbon emission rate for the i^{th} model year. Emission factors for this source are reported in Table D.4-14. Crankcase and evaporative emissions must be combined before applying equation D.4-2.

m_{in} = The weighted annual travel of the i^{th} model year vehicle during calendar year (n)

Table D.4-14. CRANKCASE AND EVAPORATIVE HYDROCARBON EMISSION FACTORS FOR HEAVY-DUTY, GASOLINE-POWERED VEHICLES EMISSION FACTOR RATING: B

Location	Model years	Crankcase emissions[b]		Evaporative emissions[a]	
		g/mi	g/km	g/mi	g/km
All areas except high altitude and California	Pre-1968	5.7	3.5	5.8	3.6
	Post-1967[c]	0.0	0.0	5.8	3.6
California only	Pre-1964	5.7	3.5	5.8	3.6
	Post-1963[c]	0.0	0.0	5.8	3.6
High altitude	Pre-1968	5.7	3.5	7.4	4.6
	Post-1967[c]	0.0	0.0	7.4	4.6

[a] References 4 through 6 were used to estimate evaporative emission factors for heavy-duty vehicles (HDV). The formula from section 3.1.2.5 was used to calculate g/mi (g/km) values, (evaporative emission factor = g + kd). The HDV diurnal evaporative emissions (g) were assumed to be three times the LDV value to account for the larger size fuel tanks used on HDV. Nine trips per day (d = number of trips per day) from Reference 3 were used in conjunction with the LDV hot soak emissions (t) to yield a total evaporative emission rate in grams per day. This value was divided by 36.2 miles per day (58.3 km/day) from Reference 1 to obtain the per mile (per kilometer) rate.

[b] Crankcase factors are from Reference 7.

[c] HDV evaporative emissions are expected to be controlled in 1978. Assume 50 percent reduction over the above post-1967 values (post-1963 California).

D.4.4 Sulfur Oxide and Particulate Emissions

Projected sulfur oxide and particulate emission factors for all model year heavy-duty, gasoline-powered vehicles are presented in Table D.4-15. Sulfur oxides factors are based on fuel sulfur content and fuel consumption. (Sulfuric acid emissions are between 1 and 3 percent of sulfur oxides emissions.) Tire-wear particulate factors are based on automobile test results, a premise necessary because of the lack of data for heavy-duty vehicles. Truck tire wear is likely to result in greater particulate emission than that for automobiles because of larger tires, heavier loads on tires, and more tires per vehicle. Although the factors presented in Table D.4-15 can be adjusted for the number of tires per vehicle, adjustments cannot be made to account for the other differences.

Table D.4-15. SULFUR OXIDES AND PARTICULATE
EMISSION FACTORS FOR HEAVY-DUTY,
GASOLINE-POWERED VEHICLES
EMISSION FACTOR RATING: B

Pollutant	Emissions	
	g/mi	g/km
Particulate		
Exhaust[a]	0.91	0.56
Tire wear[b]	0.20T	0.12T
Sulfur oxides[c] (SO_x as SO_2)	0.36	0.22

[a] Calculated from the Reference 8 value of 12 lb/10^3 gal (1.46 g/liter) gasoline. A 6.0 mi/gal (2.6 km/liter) value from Reference 9 was used to convert to a per kilometer (per mile) emission factor.

[b] Reference 10. The data from this reference are for passenger cars. In the absence of specific data for heavy-duty vehicles, they are assumed to be representative of truck-tire-wear particulate. An adjustment is made for trucks with more than four tires. T equals the number of tires divided by four.

[c] Based on an average fuel consumption of 6.0 mi/gal (2.6 km/liter) from Reference 9, on a 0.04 percent sulfur content from References 11 and 12, and on a density of 6.1 lb/gal (0.73 kg/liter) from References 11 and 12.

D.4.5 Basic Assumptions

Emission factors for heavy-duty vehicles (HDV) are based on San Antonio Road Route data for controlled (1970-1973 model years) trucks[13] and for uncontrolled (pre-1970 model years) trucks.[14] Unpublished data on 1974 trucks and technical judgment were used to estimate emission factors for post-1973 HDV. In doing so, it was assumed that diesel trucks will take over most of the "heavy" HDV market (trucks weighing more than 13,000 kg) and that the average weight of a gasoline-powered HDV will be approximately 26,000 lbs (11,790 kg). It is expected that interim standards for HDV, which will result in significant HC reduction, will be implemented in 1978.

Projected emission factors at high altitude and for the State of California are not reported in these tables; however, they can be derived using the following methodologies. Although all pre-1975 model year HDV emission factors for California vehicles are the same as those reported in these tables, the hydrocarbon and nitrogen oxides values for 1975-1977 model years in California can be assumed equal to the national (tabulated) values for the 1978 model year. Carbon monoxide levels for 1975-1977 HDV in California can be assumed to be 9 percent lower than the 1975-1977 national levels. To convert the national HDV levels for high altitude for all pollutants in a given calendar year, the light-duty vehicle (LDV) ratio of high altitude to low altitude emission factors (by pollutant) can be used. For pre-1970 model year trucks, the pre-1968 model year LDV ratio can be applied. For 1970-1973 model year trucks, the 1968 model year LDV ratio can be applied. For 1974-1977 trucks, the 1970 LDV ratio can be applied. For post-1977 trucks, the 1975 model year LDV ratio can be applied. See section D.1 of this appendix to obtain the data necessary to calculate these ratios.

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D.5 HEAVY-DUTY, DIESEL-POWERED VEHICLES

D.5.1 General

This class of vehicles includes all diesel vehicles with a gross vehicle weight (GVW) of more than 6000 lb (2772 kg). On the highway, heavy-duty diesel engines are primarily used in trucks and buses. Diesel engines in any application demonstrate operating principles that are significantly different from those of the gasoline engine.

D.5.2 Emissions of Carbon Monoxide, Hydrocarbons, and Nitrogen Oxides

Emissions from heavy-duty, diesel-powered vehicles during a calendar year (n) and for a pollutant (p) can be approximately calculated using:

$$e_{nps} = \sum_{i=n-12}^{n} c_{ipn} \, m_{in} \, v_{ips} \qquad \text{(D.5-1)}$$

where: e_{nps} = Composite emission factor in g/mi (g/km) for calendar year (n), pollutant (p), and average speed (s)

c_{ipn} = The emission rate in g/mi (g/km) for the i^{th} model year vehicles in calendar year (n) over a transient urban driving schedule with average speed of approximately 18 mi/hr

m_{in} = The fraction of total heavy-duty diesel miles (km) driven by the i^{th} model year vehicles during calendar year (n)

v_{ips} = The speed correction factor for the i^{th} model year heavy-duty diesel vehicles for pollutant (p) and average speed (s)

Values for c_{ipn} are given in Table D.5-1; values for m_{in} are in Table D.5-2. The speed correction factor (v_{ips}) can be computed using data in Table D.5-3. Table D.5-3 gives heavy-duty diesel HC, CO, and NO_x emission factors in grams per minute for idle operation, for an urban route with average speed of 18 mi/hr (29 km/hr), and for operation at an over-the-road speed of 60 mi/hr (97 km/hr).

Table D.5-1. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR HEAVY-DUTY DIESEL-POWERED VEHICLES BY CALENDAR YEAR

Pollutant	Model year	Emission factors by calendar year[a]																			
		1973		1974		1975		1976		1977		1978		1979		1980		1985		1990	
		g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km
Carbon monoxide	All	28.7	17.8	28.7	17.8	28.7	17.8	28.7	17.8	28.7	17.8	28.7	17.8	28.7	17.8	28.7	17.8	28.7	17.8	28.7	17.8
Hydrocarbons	All	4.6	2.9	4.6	2.9	4.6	2.9	4.6	2.9	4.6	2.9	4.6	2.9	4.6	2.9	4.6	2.9	4.6	2.9	4.6	2.9
Nitrogen oxides	Pre-1978	20.9	13.0	20.9	13.0	20.9	13.0	20.9	13.0	20.9	13.0	20.9	13.0	20.9	13.0	20.9	13.0	20.9	13.0	20.9	13.0
	1978											18.1	11.2	19.0	11.8	19.9	12.4	20.9	13.0	20.9	13.0
	1979													18.1	11.2	19.0	11.8	20.9	13.0	20.9	13.0
	1980															18.1	11.2	20.9	13.0	20.9	13.0
	1981																	20.9	13.0	20.9	13.0
	1982																	20.8	12.9	20.9	13.0
	1983																	19.9	12.4	20.9	13.0
	1984																	19.0	11.8	20.9	13.0
	1985																	18.1	11.2	20.9	13.0
	1986																			20.9	13.0
	1987																			20.8	12.9
	1988																			19.9	12.4
	1989																			19.0	11.8
	1990																			18.1	11.2

[a] Reference 1.

Table D.5-2. SAMPLE CALCULATION OF FRACTION OF ANNUAL HEAVY-DUTY, DIESEL-POWERED VEHICLE TRAVEL BY MODEL YEAR

Age, years	Fraction of total vehicles in use nationwide (a)[a]	Average annual miles driven (b)[b]	a x b	Fraction of annual travel (m)[c]
1	0.077	70,000	5,390	0.096
2	0.135	70,000	9,450	0.169
3	0.134	70,000	9,380	0.168
4	0.131	70,000	9,170	0.164
5	0.099	62,000	6,138	0.110
6	0.090	50,000	4,500	0.080
7	0.082	46,000	3,772	0.067
8	0.062	43,000	2,666	0.048
9	0.045	42,000	1,890	0.034
10	0.033	30,000	990	0.018
11	0.025	25,000	625	0.011
12	0.015	25,000	375	0.007
$\geq$13	0.064	25,000	1,600	0.029

[a] Vehicles in use by model year as of 1972 (Reference 2).

[b] Reference 2.

[c] $m = ab/\Sigma ab$.

Table D.5-3. EMISSION FACTORS FOR HEAVY-DUTY, DIESEL-POWERED VEHICLES UNDER DIFFERENT OPERATING CONDITIONS[a]
(g/min)
EMISSION FACTOR RATING: B

	Operating mode		
Pollutant	Idle	Urban (18 mi/hr; 29 km/hr)	Over-the-road (60 mi/hr; 97 km/hr)
Carbon monoxide	0.64	8.61	5.40
Hydrocarbons	0.32	1.38	2.25
Nitrogen oxides (NO_x as NO_2)	1.03	6.27	28.3

[a] Data are obtained by analysis of results in Reference 1.

For average speeds less than 18 mi/hr (29 km/hr), the correction factor is:

$$v_{ips} = \frac{\text{Urban} + \left(\frac{18}{S} - 1\right)\text{Idle}}{\text{Urban}} \qquad \text{(D.5-2)}$$

Where: s is the average speed of interest (in mi/hr), and the urban and idle values (in g/min) are obtained from Table D.5-3. For average speeds above 18 mi/hr (29 km/hr), the correction factor is:

$$v_{ips} = \frac{\frac{18}{42S}\left[(60\text{-}S)\ \text{Urban} + (S\text{-}18)\ \text{Over the Road}\right]}{\text{Urban}} \qquad \text{(D.5-3)}$$

Where: S is the average speed (in mi/hr) of interest. Urban and over-the-road values (in g/min) are obtained from Table D.5-3. Emission factors for heavy-duty diesel vehicles assume all operation to be under warmed-up vehicle conditions. Temperature correction factors, therefore, are not included because ambient temperature has minimal effects on warmed-up operation.

D.5.3 Emissions of Other Pollutants

Emissions of sulfur oxides, sulfuric acid, particulate, aldehydes, and organic acids are summarized in Table D.5-4.

Table D.5-4. SULFUR OXIDES, PARTICULATE, ALDEHYDES, AND ORGANIC ACIDS EMISSION FACTORS FOR HEAVY-DUTY, DIESEL-POWERED VEHICLES
EMISSION FACTOR RATING: B

Pollutant	Emissions[a]	
	g/mi	g/km
Particulate	1.3	0.81
Sulfur oxides[b] (SO_x as SO_2)	2.8	1.7
Aldehydes (as HCHO)	0.3	0.2
Organic acids	0.3	0.2

[a] Reference 3. Particulate does not include tire wear; see heavy-duty gasoline vehicle section for tire wear emission factors.

[b] Data based on assumed fuel sulfur content of 0.20 percent. A fuel economy of 4.6 mi/gal (2.0 km/liter) was used from Reference 4. Sulfuric acid emissions range from 0.5 - 3.0 percent of the sulfur oxides emissions, with the best estimate being 1 percent. These estimates are based on engineering judgment rather than measurement data.

D.5.4 Basic Assumptions

Hydrocarbon and carbon monoxide levels for heavy-duty diesel vehicles until model year 1978 are given by Reference 1. An interim standard for diesel HDV that will restrict nitrogen oxides levels, but not hydrocarbon or carbon monoxide levels, is expected to be implemented in 1978. For purposes of the projections, the nitrogen oxides standard was assumed to be 9 grams per brake horsepower per hour. Nitrogen oxide emission standards in California for 1975-1977 model year HDV are assumed to be equivalent to the national levels in 1978; hydrocarbon and carbon monoxide levels in California will be the same as national levels. A separate table is not given for California, but emissions are the same at those reported in Table D.5-1, with the exception of the 1975-1977 model years. It is assumed that the effect of altitude on diesel emissions is minimal and can be considered negligible.[3]

References for Section D.5

1. Ingalls, M. N. and K. J. Springer. Mass Emissions from Diesel Trucks Operated Over a Road Course. Southwest Research Institute, San Antonio, Texas. Prepared for Environmental Protection Agency, Ann Arbor, Mich. Under Contract No. 68-01-2113. Publication No. EPA-460/3-74-017. August 1974.

2. Census of Transportation. Truck Inventory and Use Survey. Department of Commerce, Bureau of the Census, Washington, D. C. 1974.

3. Young T. C. Unpublished emission factor data on diesel engines. Engine Manufacturers Association Emission Standards Committee, Chicago, Ill. October 16, 1974.

4. Truck and Bus Fuel Economy. U. S. Department of Transportation, Cambridge, Mass. and Environmental Protection Agency, Ann Arbor, Mich. November 1974.

D.6 MOTORCYCLES

D.6.1 General

Motorcycles are becoming an increasingly popular mode of transportation as reflected by steady increases in sales over the past few years. A detailed discussion of motorcycles may be found in section 3.1.7.

D.6.2 Carbon Monoxide, Hydrocarbon, and Nitrogen Oxides Exhaust Emissions

The composite exhaust emission factor is calculated using:

$$e_{nps} = \sum_{i=n-12}^{n} c_{ipn} \, m_{in} \, v_{ips} \qquad \text{(D.6-1)}$$

where: e_{nps} = Composite emission factor in g/mi (g/km) for calendar year (n), pollutant (p), and average speed (s)

c_{ipn} = The test procedure emission factor for pollutant (p) in g/mi (g/km) for the ith model year in calendar year (n)

m_{in} = The weighted annual travel of the ith model year vehicles during calendar year (n). The determination of this variable involves the use of the vehicle year distribution.

v_{ips} = The speed correction factor for the ith model year vehicles for pollutant (p) and average speed (s)

The emission factor results of the Federal Test Procedure (c_{ipn}) as modified for motorcycles are summarized in Tables D.6-1 through D.6-6. Table D.6-7 contains a sample calculation of the variable m_{in} using nationwide statistics.[2] Because there are no speed correction factor data for motorcycles, the variable v_{ips} will be assumed to equal one. The emission factor for particulate, sulfur oxide, and aldehyde and for crankcase and evaporative hydrocarbons are presented in Table D.6-8.

Table D.6-1. PROJECTED CARBON MONOXIDE, HYDROCARBON AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR MOTORCYCLES FOR PRE-1977 AND 1977 CALENDAR YEARS

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1977[a,b]	30.6	19.0	8.1	5.0	0.2	0.1
1977[b]	28.0	17.4	5.0	3.1	0.25	0.16

[a] Factors for pre-1977 calendar years.
[b] Factors for calendar year 1977.

Table D.6-2. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR MOTORCYCLES FOR CALENDAR YEAR 1978

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1977	30.6	19.0	8.1	5.0	0.2	0.1
1977	29.4	18.3	5.5	3.4	0.25	0.16
1978	28.0	17.4	5.0	3.1	0.25	0.16

Table D.6-3. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR MOTORCYCLES FOR CALENDAR YEAR 1979

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1977	30.6	19.0	8.1	5.0	0.2	0.1
1977	30.6	19.0	6.0	3.7	0.25	0.16
1978	29.4	18.3	5.5	3.4	0.25	0.16
1979	28.0	17.4	5.0	3.1	0.25	0.16

Table D.6-4. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR MOTORCYCLES FOR CALENDAR YEAR 1980

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1977	30.6	19.0	8.1	5.0	0.2	0.1
1977	30.6	19.0	6.5	4.0	0.25	0.16
1978	30.6	19.0	6.0	3.7	0.25	0.16
1979	29.4	18.3	5.5	3.4	0.25	0.16
1980	28.0	17.4	5.0	3.1	0.25	0.16

Table D.6-5. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR MOTORCYCLES FOR CALENDAR YEAR 1985

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1977	30.6	19.0	8.1	5.0	0.2	0.1
1977	30.6	19.0	8.1	5.0	0.25	0.16
1978	30.6	19.0	8.1	5.0	0.25	0.16
1979	30.6	19.0	8.0	5.0	0.25	0.16
1980	30.6	19.0	7.5	4.7	0.25	0.16
1981	30.6	19.0	7.0	4.3	0.25	0.16
1982	30.6	19.0	6.5	4.0	0.25	0.16
1983	30.6	19.0	6.0	3.7	0.25	0.16
1984	29.4	18.3	5.5	3.4	0.25	0.16
1985	2.1	1.3	0.41	0.25	0.4	0.2

Table D.6-6. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR MOTORCYCLES FOR CALENDAR YEAR 1990

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
1977	30.6	19.0	8.1	5.0	0.25	0.16
1978	30.6	19.0	8.1	5.0	0.25	0.16
1979	30.6	19.0	8.1	5.0	0.25	0.16
1980	30.6	19.0	8.1	5.0	0.25	0.16
1981	30.6	19.0	8.1	5.0	0.25	0.16
1982	30.6	19.0	8.1	5.0	0.25	0.16
1983	30.6	19.0	8.1	5.0	0.25	0.16
1984	30.6	19.0	8.0	5.0	0.25	0.16
1985	3.1	1.9	0.81	0.50	0.4	0.25
1986	2.9	1.8	0.73	0.45	0.4	0.25
1987	2.7	1.7	0.65	0.40	0.4	0.25
1988	2.5	1.6	0.57	0.35	0.4	0.25
1989	2.3	1.4	0.49	0.30	0.4	0.25
1990	2.1	1.3	0.41	0.25	0.4	0.25

Table D.6-7. SAMPLE CALCULATION OF FRACTION OF ANNUAL MOTORCYCLE TRAVEL BY MODEL YEAR

Age, years	Fraction of total vehicles in use nationwide (a)[a]	Average annual miles driven (b)[b]	a x b	Fraction of annual travel (m)[c]
1	0.04	2,500	100	0.064
2	0.20	2,100	420	0.268
3	0.19	1,800	342	0.218
4	0.16	1,600	256	0.163
5	0.10	1,400	140	0.089
6	0.09	1,200	108	0.069
7	0.05	1,100	55	0.035
8	0.03	1,000	30	0.019
9	0.03	950	29	0.019
10	0.02	900	18	0.011
11	0.0005	850	4	0.003
≥12	0.085	800	68	0.043

[a] Vehicles in use by model year as of 1974 (Reference 2).

[b] Reference 2.

[c] $m = ab/\Sigma ab$.

Table D.6-8. SULFUR OXIDE, ALDEHYDE, AND CRANKCASE AND EVAPORATIVE HYDROCARBON EMISSION FACTORS FOR MOTORCYCLES[a]

Pollutant	Emissions			
	2-stroke engine		4-stroke engine	
	g/mi	g/km	g/mi	g/km
Hydrocarbons				
Crankcase[b]	–	–	0.60	0.37
Evaporative[c]	0.36	0.22	0.36	0.22
Particulates	0.33	0.21	0.046	0.029
Sulfur oxides[d] (SO_x as SO_2)	0.038	0.024	0.022	0.014
Aldehydes (RCHO as HCHO)	0.11	0.068	0.047	0.029

[a] Reference 1.

[b] Most 2-stroke engines use crankcase induction and produce no crankcase losses.

[c] Evaporative emissions were calculated assuming that carburetor losses were negligible. Diurnal breathing of the fuel tank (a function of fuel vapor pressure, vapor space in the tank, and diurnal temperature variation) was assumed to account for all the evaporative losses associated with motorcycles. The value presented is based on average vapor pressure, vapor space, and temperature variation.

[d] Calculated using a 0.043 percent sulfur content (by weight) for regular fuel used in 2-stroke engines and 0.022 percent sulfur content (by weight) for premium fuel used in 4-stroke engines.

D.6.3 Basic Assumptions

Baseline emission data are from Reference 1. The motorcycle population was assumed to be 60 percent 4-stroke and 40 percent 2-stroke.

For the interim standards, deterioration factors for 1977 through 1984 were assumed to be: 10 percent per calendar year for hydrocarbons, 5 percent per calendar year for carbon monoxide, and 0 percent per calendar year for nitrogen oxides. For 1985 and beyond, deterioration factors are: 20 percent per calendar year for hydrocarbon, 10 percent per calendar year for carbon monoxide, and 0 percent per calendar year for nitrogen oxides. Motorcycles are assumed to deteriorate until they reach uncontrolled emission values. The deterioration rate is a fixed percentage of base year emissions.

References for Section D.6

1. Hare, C. T. and K. J. Springer. Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines. Part III, Motorcycles. Final Report. Southwest Research Institute, San Antonio, Texas. Prepared for Environmental Protection Agency, Research Triangle Park, N. C. under Contract No. EHS 70-108. Publication No. APTD-1492. March 1973.

2. Motorcycle Usage and Owner Profile Study. Hendrix, Tucker and Walder, Inc., Los Angeles, Calif. March 1974.

D.7 ALL HIGHWAY VEHICLES

D.7.1 General

Emission factors for 1972 for all major classes of highway vehicle are summarized in section 3.1.1. A number of scenarios that embody a range of local conditions, such as different ambient temperatures and average route speeds, are considered. Although similar data for calendar years 1973 through 1990 are presented here, only one scenario is presented. This single scenario is presented because it is general in nature and, therefore, most appropriate for a range of applications. The authors, however, believe that projections of any significance should be based on the data and methodologies presented in sections D.1 through D.6 of this appendix. The data presented in this section are, clearly, only approximations and are useful only for rough estimates.

The scenario considers the four major highway vehicle classes: light-duty, gasoline-powered vehicles (LDV); light-duty, gasoline-powered trucks (LDT); heavy-duty, gasoline-powered vehicles (HDV); and heavy-duty, diesel-powered vehicles (HDD). An average route speed of approximately 19.6 mi/hr (31.6 km/hr) is assumed. The ambient temperature is assumed to be 24°C (75°F). Twenty percent of LDV and LDT operation is considered to be in a cold operation; all HDV and HDG operation is taken to be in warmed-up condition. The percentage of total vehicular travel by each of the vehicle classes is based on nationwide data.[1,2] The percentage of travel by class is assumed to be 80.4 percent by LDV, 11.8 percent by LDT, 4.6 by HDV, and 3.2 percent by HDD.

D.7.2 Emissions

Emissions for the five pollutants for all highway vehicles are presented in Table D.7-1. The results are only an approximate indication of how future emission-controlled vehicles will influence the overall emissions from the fleet of vehicles on the road. These values do not apply to high altitude areas, nor do they apply to vehicles in the State of California.

Table D.7-1. AVERAGE EMISSION FACTORS FOR HIGHWAY VEHICLES FOR SELECTED CALENDAR YEARS

Calendar year	Carbon monoxide		Hydrocarbons		Nitrogen oxides		Sulfur oxides[a]		Particulate	
	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km
1973	71.5	44.4	10.1	6.3	4.9	3.0	0.23	0.14	0.61	0.38
1974	67.5	41.9	9.4	5.8	4.8	3.0	0.23	0.14	0.61	0.38
1975	61.1	37.9	8.8	5.5	4.8	3.0	0.23	0.14	0.59	0.37
1976	54.6	33.9	8.0	5.0	4.8	3.0	0.22	0.14	0.57	0.35
1977	48.3	30.0	7.2	4.5	4.6	2.9	0.22	0.14	0.54	0.34
1978	42.7	26.5	6.6	4.1	4.3	2.7	0.21	0.13	0.51	0.32
1979	36.8	22.9	6.1	3.8	3.9	2.4	0.21	0.13	0.49	0.30
1980	31.0	19.3	5.4	3.4	3.6	2.2	0.20	0.12	0.47	0.29
1985	15.7	9.8	2.7	1.7	2.4	1.5	0.19	0.12	0.41	0.25
1990	11.3	7.0	1.9	1.2	2.0	1.2	0.19	0.12	0.40	0.25

[a] Fuel sulfur levels may be reduced in the future. If so, sulfur oxides emissions will be reduced proportionately.

References for Section D.7.

1. Highway Statistics 1971. U.S. Department of Transportation, Federal Highway Administration, Washington, D. C. 1972. p. 81
2. 1972 Census of Transportation. Truck Inventory and Use Survey. U.S. Department of Commerce, Bureau of the Census, Washington, D.C. 1974.